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ENGINEERING JOURNAL

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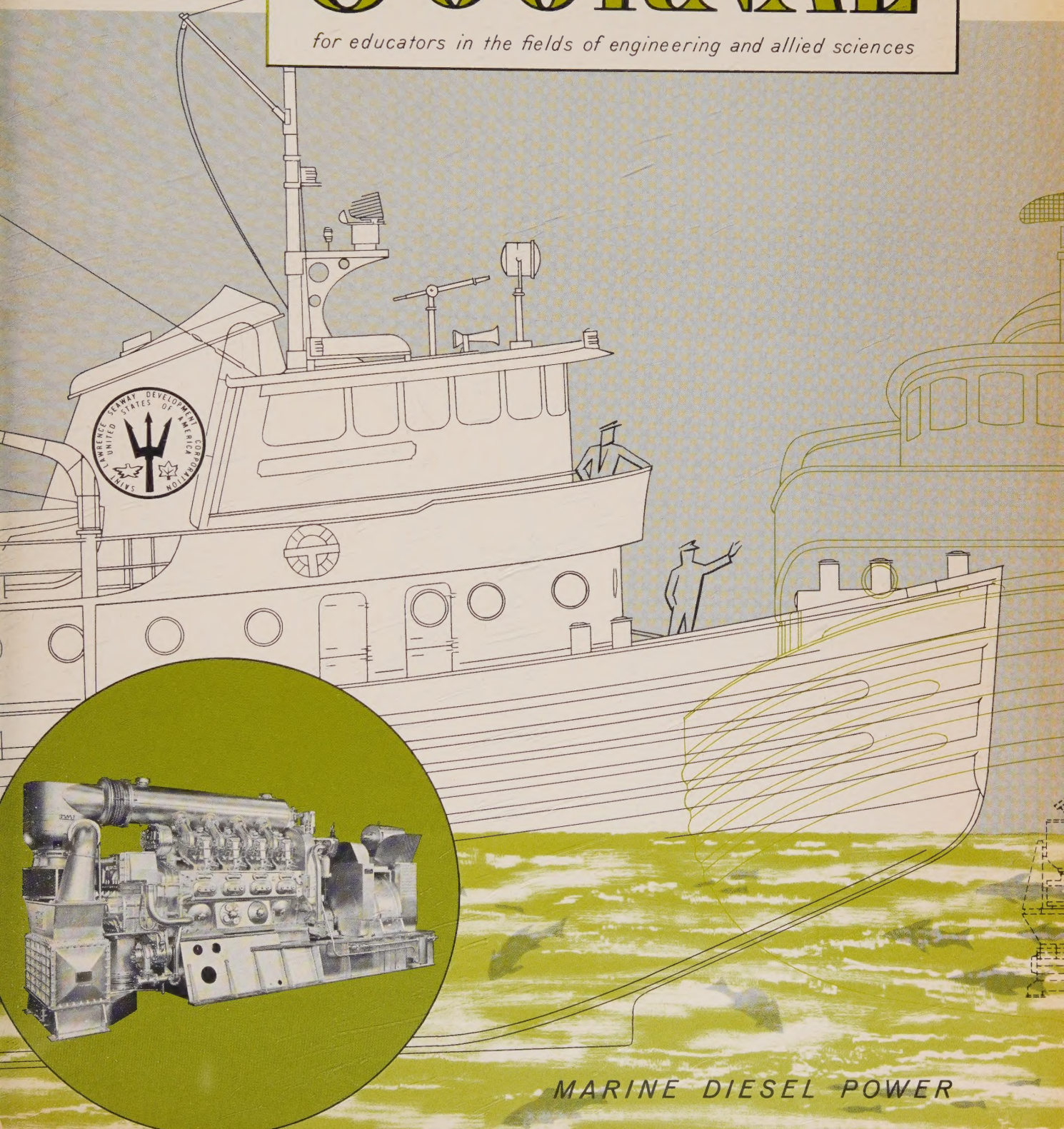
for educators in the fields of engineering and allied sciences



MARINE DIESEL POWER

On Fences and Engineering

FENCES along property boundary lines enable an owner to exercise his legal rights over his land according to his own motives and interests.

A student must have a goal for his formal education and follow this goal to its attainment. This necessarily involves concentration in specific areas of study. Thus, temporary mental fences are desirable at certain stages of the student's educational progress.

Fortunately for the growth of the human spirit, mental fences in the truly educated mind are not permanent. They, too, mark temporary boundaries and are moved as tomorrow's problems direct.

The engineering student confines his thinking during his undergraduate period principally to one engineering area, say electrical engineering. Once this objective—gaining the degree in electrical engineering—is achieved, he may find in his employment that the solution of a problem requires knowledge or experience in other engineering areas, such as chemistry or metallurgy. This presents a challenge to broaden his field of interest and remove some of the temporary fences.

We find many instances in General Motors where the engineer enters fields of engineering other than that of his original goal. For example, a mechanical engineer working on basic problems of removing metal found that his greatest contribution was in the field of electrical engineering.

Metallurgical engineers evaluating quenching media used the principle of magnetism to develop an electronic device to measure the heat extraction properties of liquids. A mechanical engineering graduate now heads up laboratories investigating processing problems in heat treating, welding, and plating. Another mechanical engineer heads up metal casting laboratories.

Sometimes an interest in another field may lead the individual so far outside his formal educational boundaries that he finds his contribution and personal satisfaction are greatest in this new field.

In one GM Division, a graduate metallurgical engineer progressed to the position of assistant chief engineer in charge of an engineering group working on electrical product design. Subsequently, he was placed in charge of manufacturing for this Division.

Although most engineering college curricula lead to a degree in one specific field of engineering, the basic science and mathematics courses provide the background for a broad approach to engineering problems. Thus, a student should look forward to progressing in his own field, but with the possibility that he will find the greatest challenges and make the most contributions to his own and his employer's progress in other fields of engineering and science.

After earning his degree the engineer has the freedom to expand his interests and abilities beyond the former limits set by his studies. His is an educated mind with movable fences.

R M Critchfield

Robert M. Critchfield,
Vice President in Charge of
Process Development Staff

THE COVER

Diesel-electric power plants have found widespread marine application because of their flexibility and high torque output. The Diesel engine provides good fuel economy and the electric propulsion motor eliminates many disadvantages of direct drive. With an electric drive, engine speed is not affected by propeller speed; flexibility of engine placement eliminates compromise between propulsion and design requirements; and maneuverability is increased greatly because of simple, remote controls.

This issue's cover, designed by artist Ernest W. Scanes, depicts a recent marine application of Diesel-electric power in the *Robinson Bay*, the first tug to be delivered to the Saint Lawrence Seaway Development Corporation. The power plant for the tug is the Model 498 eight-cylinder, turbocharged two-cycle Diesel engine, manufactured by the Cleveland Diesel Engine Division. The engine, direct-connected to a 970-kw generator, is rated at 1,400 bhp at 800 rpm, and provides the tug with adequate power for its duties of handling heavy equipment, tending buoys, and ice breaking.

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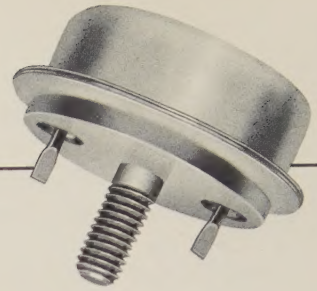
The Application of High Power Transistors to Audio Circuitry



In many electronic applications, the transistor is successfully replacing the vacuum tube. The transistor is not a competitive device in the sense that it can be interchanged directly with tubes. Instead, the transistor requires independent circuit development. Some factors which distinguish transistors from tubes are: moderate internal operating temperatures; conduction processes within a solid instead of a vacuum; and low internal impedances. Since transistor properties vary with temperature, temperature characteristics must be investigated to determine the limits of satisfactory operation. Because of electrical stresses in solids, voltage limits need to be established. Due to low input impedance, the transistor requires power from the driving source, which makes circuit design critical regarding impedance matching and power gain. In audio circuitry employing transistors, all of these considerations are important. As in most cases, however, certain compromises must be made to obtain a final circuit which is suited to the application.

EARLY transistor audio circuitry came into prominence first with hearing aids and later with personal portable radios. In these applications the power output requirements were from 1 mw to 100 mw. The small size and low power drain associated with these low power transistors were of prime importance. Indeed, the general public now is conditioned to think of transistors as being extremely small in size and having low power drain. These are popular impressions that need to be modified when thinking of power transistors.

With greater power output, larger physical size and increased power drain must be accepted. The physical size in this case, however, is associated mainly with the heat dissipator on which the transistor is mounted. The transistor itself is still considerably smaller than the vacuum tube equivalent. In the automobile radio field, audio power output from 2 watts to 10 watts is now general. In other possible applications, such as high fidelity amplifiers or public address systems for automobile installation, audio power requirements may range from 10 watts to 50 watts.

This paper is concerned with a study by Delco Radio Division engineers of PNP alloyed junction transistors used in audio circuits requiring high power output[1]. The data gathered during the study consisted of results obtained by actual measurements on transistor circuits. Of the three possible transistor circuit configurations, *common emitter*, *common collector*, and *common base*, only the first two were studied. The common base connection has been included in some of the discussion for completeness, but because of its low power gain no measurements were made with this circuit. Delco 2N173 type transistors were used in all measurements.

The results of this study help in understanding some of the basic problems encountered in designing audio circuits. The problems can be divided into two parts: (a) power gain considerations, and (b) harmonic distortion considerations. Actually, a third major consideration is encountered in the limitations of the transistor itself. These limitations arise from the temperature and voltage effects on the germanium base material, and must be considered in any final circuit design. A discussion of these limitations, however, is not included in this paper.

Power Gain Important to Audio Circuits

The performance of a power output stage is specified by audio output in watts and power gain in decibels. For maximum power outputs ranging from 1 to 20 watts, the load resistances to be used with single-ended or push-pull amplifiers vary greatly for a given supply voltage (Fig. 1). The term *maximum output* is used to define the power level at which symmetrical clipping, or saturation of the output voltage peaks, is first observed.

Factors Affecting Gain

The power gain of the amplifier circuit varies with two factors: (a) the type of circuit connection used, and (b) the load resistance (Fig. 2). For single-ended circuits the power gain in the common emitter circuit is much higher than for the common collector circuit. This shows the dependence of gain upon the type of connection used. The dependence of gain upon load resistance is illustrated by the common emitter curve (Fig. 2) which shows gain decreasing as the load resistance is reduced. For the common collector connection, in theory, the power gain should be independent of load. An actual drop-off in power gain is caused by the decrease in current gain which occurs as the transistor operating current

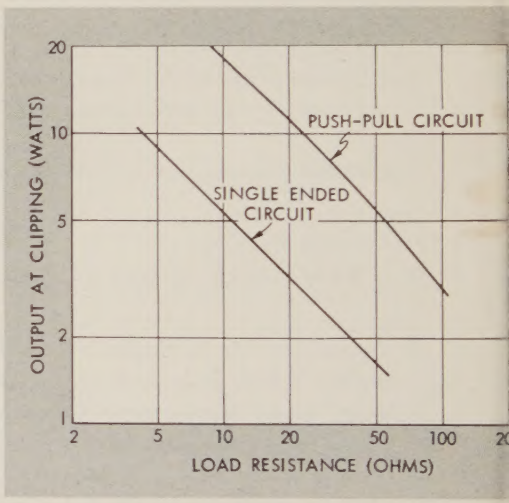


Fig. 1—This graph shows what output power may be obtained for given load impedances with either single-ended or push-pull circuits. These data apply only for 12-volt power supplies and inductive coupled loads. The loads may be considered as reflected transformer impedances or actual load resistances shunted with a choke. The data also include typical circuit losses due to such factors as transformer resistances and transistor resistances. The output at *clipping* is the wattage obtained when the output voltage waveform first shows saturation or flattening on both peaks simultaneously.

By DONALD O. RUFF
Delco Radio
Division

Power gain and harmonic distortion—major factors affecting circuit design

increases.

An examination of dependence of gain upon the type of circuit and the load impedance for push-pull common emitter amplifiers, (Fig. 2) shows that, for any given load, slightly more gain is obtained in Class A operation than in Class B operation. Also, a decrease in gain as

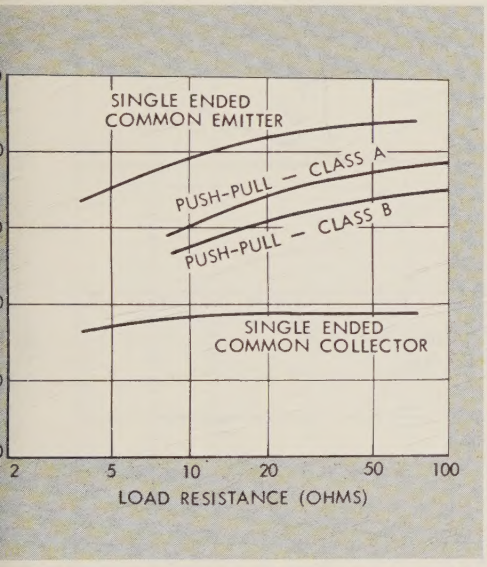


Fig. 2—The power gain of common emitter single-ended and push-pull amplifiers and a common collector single-ended amplifier, for given load resistances, is shown on this graph. The data were taken at 400 cycles, one-watt output, with source impedances matched to the input impedances of the circuit. For any given load impedance, the transistor operating point was first optimized for maximum power output, then the gain was measured at one watt.

load resistance decreases is evident. In the common collector circuit for push-pull operation (not shown), the gain is much less than for the common emitter circuit, just as in the single-ended case.

To achieve maximum power output while keeping the operating level as low as possible for temperature reasons, it is necessary to obtain the highest practical circuit efficiency. The type of load circuit fundamentally limits the output efficiency. For pure resistance loads, the maximum theoretical output power is only 25 per cent of the d-c input power from the supply. For transformer coupled loads, the maximum theoretical output is 50 per cent for Class A operation, either single-ended or push-pull, and 78 per cent maximum for Class B push-pull. The actual power output is less than the theoretical output by the amount lost in the transformers, transistors, and the temperature stabilizing resistors. Transformer coupled loads are used on almost all present transistor power circuits because of better efficiency. Class B push-pull operation is especially attractive from the efficiency standpoint, but there are other problems associated with this circuit which will be discussed.

The Driver Circuit

The subject of power gain also should include the driver circuit preceding the output stage. In designing a driver stage, sufficient power must be obtained to supply the following transistor amplifier. Therefore, the load impedance on the driver is determined by the input impedance of the following stage.

There are two important types of driver circuits: triode and pentode. These classifications are named after vacuum tube circuits, but also include any other amplifying devices which have output characteristics similar to the plate characteristics of triode or pentode tubes. The internal impedances of these two circuits differ greatly.

Triode type drivers have lower internal impedance, generally of the same order of magnitude as the load impedance which they drive. To obtain optimum power sensitivity and optimum power output with triodes, the interstage transformer is designed to match the internal impedance to the load. The low voltage 12K5 tube, which has output characteristics resembling those of a triode, might be classified as a triode type driver.

The internal impedance of a pentode type driver is much higher than the usual load impedance. The transformer in this case reflects the proper load to the driver so that the required power output is produced with the available volt-ampere swing. An impedance match is not attempted. In addition to pentode tubes, junction transistors also would fall into this driver classification.

Harmonic Distortion Affects Circuit Design

An amplifier may be said to have low distortion when, if driven by a sine wave input, it is capable of supplying a sine wave of current to a resistive load. If negative feedback over two or more stages is excluded from consideration, then the lowest possible distortion in a transistor amplifier is a function of the transistor characteristics. This can be illustrated by the linearity of the input-output curves. Also, these curves show whether the input should be supplied as a driving voltage or as a driving current in order to operate in the most linear region. One approach is to examine the slope of the

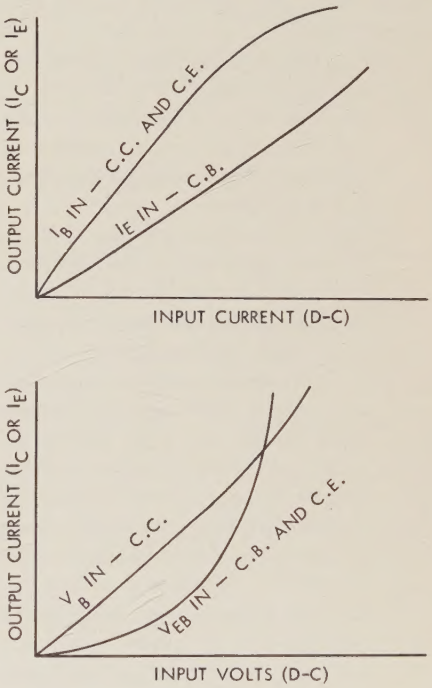


Fig. 3—Since a transistor has both an input current and an input voltage, the output current may be shown as a function of either. For the common base *C.B.* connection, the output current flows in the collector circuit I_C, the input current flows in the emitter I_E, and the input voltage is applied between emitter and base V_{EB}. For the common emitter *C.E.* connection, the output current is I_C, the input current is I_B (flows in the base), and the input voltage is applied between base and emitter V_{BE}. In the common collector *C.C.* connection, the output current is I_C, the input current is I_B, and the input voltage V_B is applied between the base and the power supply end of the load in the emitter circuit. In the a-c circuit, this point is common with the collector terminal. The input current for these characteristics is supplied from a high impedance source and the input voltage from a low impedance source as compared to the input impedance of the particular circuit.

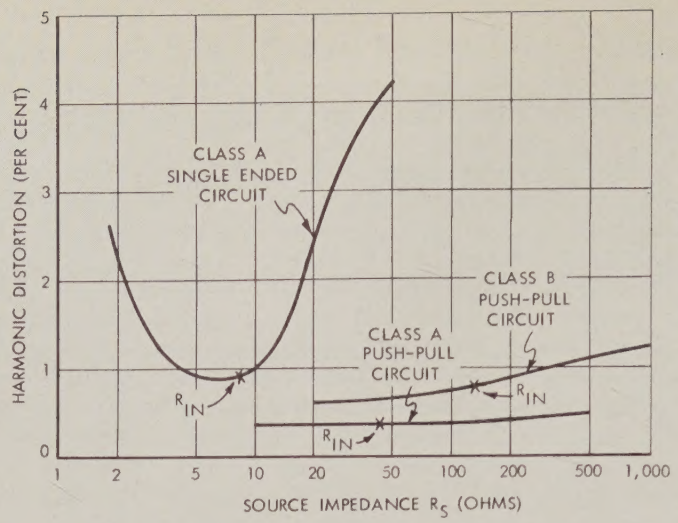


Fig. 4—The effect of source impedance upon harmonic distortion is shown here. The data were taken for 400 cycles at one-watt output. Both single-ended and push-pull circuits were connected in the common emitter configuration. The load impedance was 11 ohms for the single-ended circuit, and 25 ohms for the push-pull circuit. The input impedance to the amplifier R_{IN} is marked on each curve.

d-c characteristics of the transistor in various circuit configurations (Fig. 3), from which the following observations can be made:

- For the common base connection the input current characteristic is the most linear. This means the circuit should have a high impedance (current) source to supply the signal to the amplifier
- For the common collector connection the input voltage characteristic is the most linear. Therefore, a low impedance (voltage) source is called for to supply the a-c signal
- For the common emitter connection the current input and the voltage input curves are both non-linear, which means that neither a high impedance nor a low impedance source will give low distortion. Since the curvature of the two input curves is opposite, however, a source impedance between these limits could produce a much more linear characteristic. If the transistor is designed with this in mind, it is possible to get minimum distortion when the source impedance approximately equals the input resistance of the transistor.

Effect of Source Impedance

The common emitter circuit is of the most interest because it has the highest gain of the three possible circuit configurations. Harmonic distortion for this circuit connection has been investigated to determine the effects of source impedance upon linearity. Several results were obtained from the investigation (Fig. 4). In the case of single-ended amplifiers there is a very definite effect on distortion due to the source impedance. Distortion is minimum for source impedances near the input resistance, R_{IN}. The d-c characteristics of a single transistor (examined in Fig. 3) indicate that this result can be obtained.

In the case of the push-pull amplifier, new factors enter in. If push-pull transistors are well matched and close coupling is obtained in the two halves of the output transformer, then even order harmonics cancel out, leaving mainly odd order harmonics. Thus, push-pull circuits may produce less distortion. The curves do not extend far enough to show definitely whether a minimum distortion point versus source impedance exists as for the single-ended case. However, the source impedances that were investigated extend well above and below the input resistances, R_{IN}. Further extremes are not practical due to the loss of gain for this degree of mismatch in the coupling circuit.

Effect of Load

In addition to the effects of source impedance, harmonic distortion tends to vary with the load resistance on the transistor (Fig. 5). The operating point is optimized for each different load condition. For the common emitter circuit

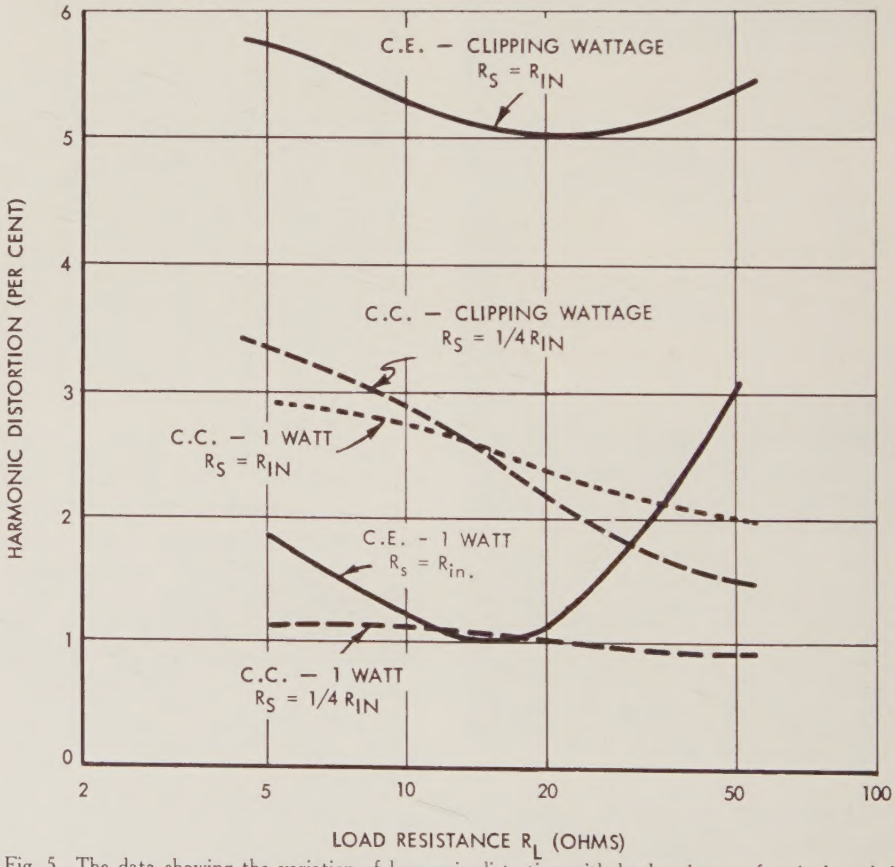


Fig. 5—The data showing the variation of harmonic distortion with load resistance for single-ended amplifiers were taken for circuits connected in common emitter and common collector configurations. The frequency of operation was 400 cycles. In the common emitter circuit, distortion was measured with source impedance matched to the input. For the common collector data, a source impedance equal to one-fourth the input impedance was used. To illustrate the necessity of a low source impedance to obtain low distortion in common collector operation, a curve for one-watt output with matched impedance is shown for comparison to the one-watt curve with low source impedance. The clipping power output for any load resistance may be obtained by referring to Fig. 1.

there is one load (or operating current) where distortion is lowest. In this case it is approximately 15 ohms at the 1-watt level, and about 20 ohms for the maximum power output level.

For the common collector curves (Fig. 5), distortion decreases as the load impedance increases. No minimum point is evident as in the case of the common emitter connection. To obtain linear operation for low distortion, the common collector data were taken with a source having one-fourth of the transistor input impedance.

For push-pull circuits, the harmonic distortion also varies with load resistance (Fig. 6). Within the limits of the data, distortion decreases in the Class A circuit with lower load resistance (higher power output). In Class B, the distortion increases rapidly as power output is raised. For load resistances less than 30 ohms, Class A is definitely better than Class B as far as distortion is concerned. It should be emphasized that temperature problems are more severe in Class A. Therefore, Class B, because of higher efficiency, may be better for some applications.

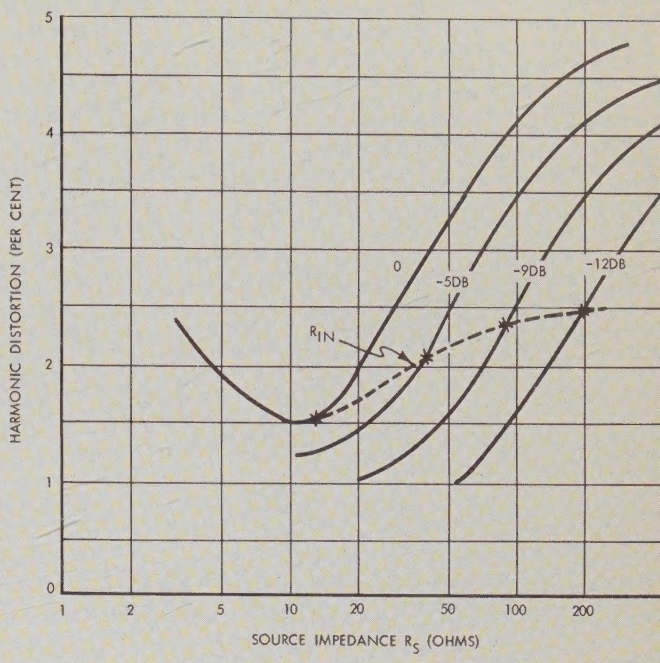


Fig. 7—This graph shows the effect of source impedance upon harmonic distortion for a typical single-ended common emitter amplifier with degeneration. The decibel notations on the curve indicate the loss of power gain due to various levels of degeneration caused by leaving the temperature stabilizing resistor in the emitter unbypassed. Measurements were made at 400 cycles, one-watt output. The input impedance for each curve has been marked, and the points connected by a dotted line. From this, it is seen that unbypassed resistance raises the input impedance. If the source is matched to the input in all cases, degeneration of this type results in increased harmonic distortion.

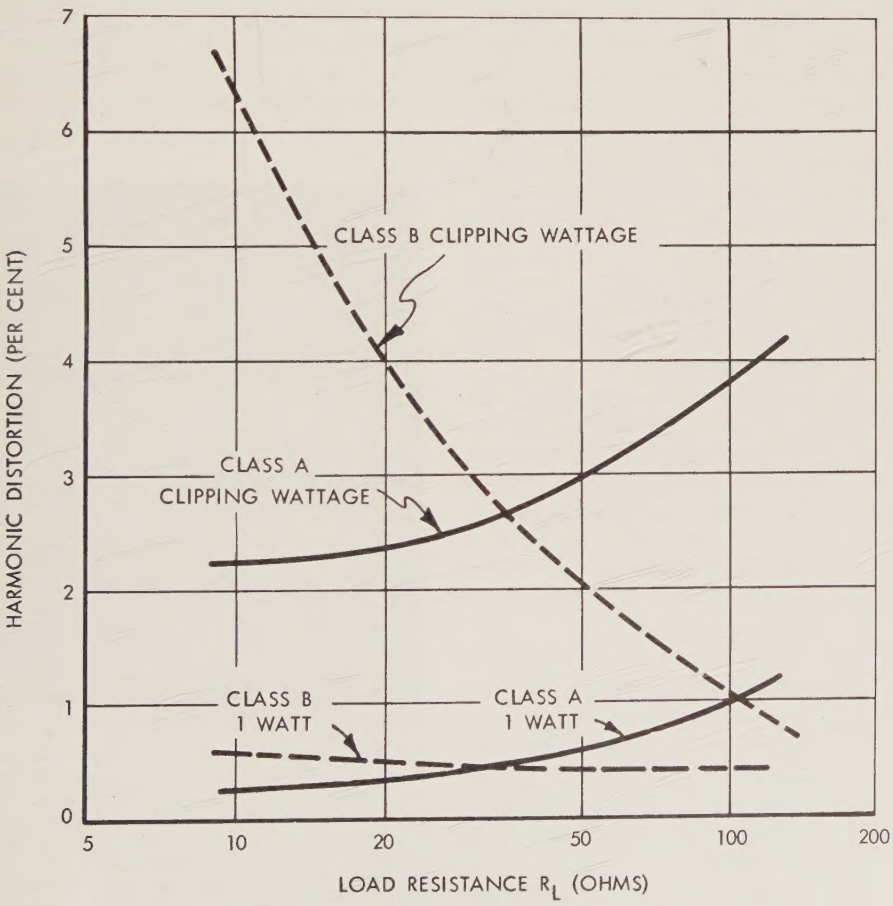


Fig. 6—Variation of harmonic distortion with load resistance for push-pull circuits in the common emitter connection for both Class A and Class B operation is shown by this graph. The source impedance was matched to the input at a frequency of 400 cycles. Distortion was measured at one-watt output and at clipping wattage.

Degenerated Common Emitter Amplifier

In all of the foregoing circuit discussion, lowest distortion has been obtained simply by operating on the most linear characteristic. Negative feedback has not been included unless the common collector circuit is considered as having 100 percent voltage feedback. The common emitter circuit appears to offer some possibility for negative feedback because of its high gain. A loss of a few decibels may not be critical if distortion is reduced for a particular application. The emitter resistance required for temperature stabilization is degenerative in the a-c circuit. To obtain feedback, it is necessary only to leave this resistance unbypassed.

To explore this possibility, curves were plotted showing harmonic distortion versus source impedance for a single-ended amplifier with various amounts of degeneration (Fig. 7). Unbypassed emitter resistance raises the input impedance to the amplifier. If the source impedance is matched to the input in each case, distortion actually increases as more feedback is used. To take advantage of the feedback to get lower distortion, the source impedance must be decreased to a value well below the input impedance.

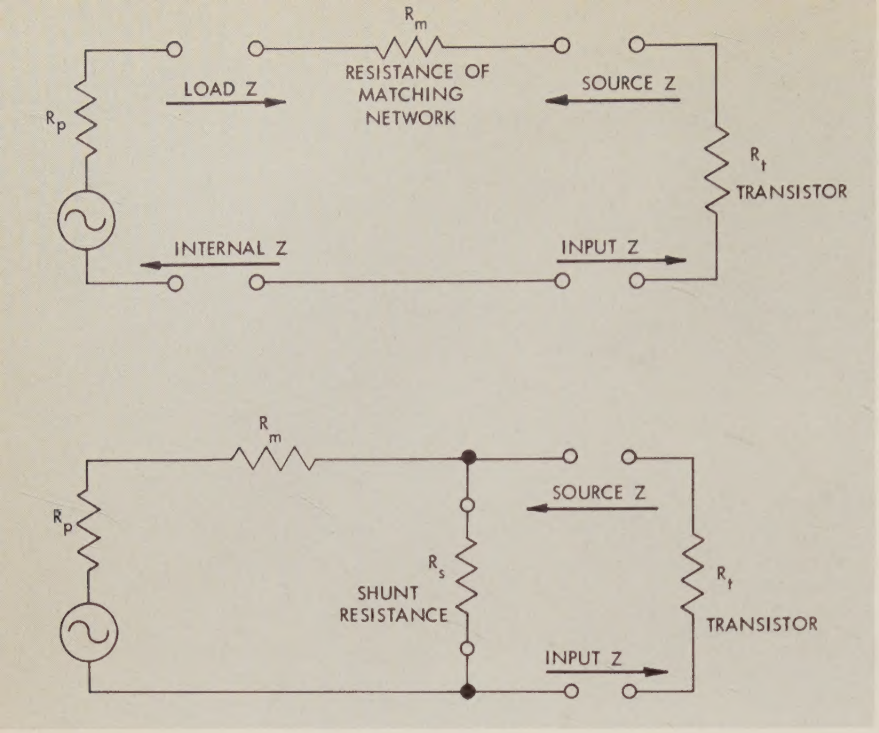


Fig. 8—Transistor input resistance R_t can be matched to the source in several ways. This figure shows matching input resistance to a triode type driver (top) and a pentode type driver (bottom). The driver internal impedance is represented by R_p, and the resistance of the matching network by R_m. With a triode type driver (top), the load impedance should be matched approximately to the internal impedance for optimum gain and power output. For common emitter operation of the transistor, the source should be matched to the input impedance of the transistor. If R_m is very much smaller than R_p or R_t, then these two conditions may be met simultaneously. If R_m is made high, or R_p is the high internal impedance of the pentode type driver, a high impedance current source is obtained. Referring to the bottom circuit, if R_p plus R_m is much greater than R_t, then the source impedance can be matched by shunting a resistance R_s equal to R_t across the source terminals. If a source impedance lower than R_t is desired, then R_s can be made smaller than R_t by any desired amount. The result would be a voltage source.

This means that not only is gain lost due to degeneration, but more gain must be lost in order to mismatch the input to get a low source impedance.

Distortion in the Driver Circuit

In the case of a single-ended driver and single-ended output stage, the signal may be phased between stages so that the second harmonic of the driver is in the phase to help cancel out the second harmonic of the output stage. This type of result is not always consistent from one amplifier to the next, and it also is subject to variation with the frequency of operation. It is a usable means, however.

One of the most difficult driver problems occurs with the Class B push-pull amplifier in either the common emitter or common collector connection. The input impedance to Class B amplifiers is resistive but very non-linear. Low distortion cannot be obtained from a linear driver stage unless it also operates into a linear load. A solution is to make the impedance of the Class B stage only a small part of the total load impedance to the driver. Once again, this means losing considerable power due to the mismatch in impedance. If the mismatch is made by paralleling additional resistance across the Class B input, then a low source impedance is obtained at the same time which also aids in getting lower distortion in the output stage.

Combined Limitations Also Affect Circuit Design

Decisions made in circuit design to favor any one of the limitations of power output, gain, or harmonic distortion, may at the same time adversely affect the others. The importance of these various factors must be assessed and a compromise in the design made accordingly. The best compromise will depend upon the particular application in question.

Gain Versus Distortion

In the single-ended amplifier, consider gain and distortion at the same time in the three configurations as follows:

(a) In the common base circuit the input impedance is very low, but for linear operation the source impedance should be high. This is the existing condition if a pentode driver is used. If a triode driver is used, low distortion calls for a mismatch which is detrimental to gain

(b) In the common collector circuit the input impedance is very high, but linear operation calls for a low source impedance. With either type driver a mismatch in impedance is necessary to obtain low distortion and once again the gain must suffer

(c) In the common emitter circuit low distortion occurs for source impedances approximating the input, so little or no gain is lost.

Matching or mismatching of the driver to the amplifier input in the desired manner may be accomplished in several ways. Matching conditions may be illustrated with the matching network appearing as a series resistance (Fig. 8). If a transformer is used, all impedances should be reflected to either the primary or secondary side. With a triode type driver, the load impedance which the driver sees should be about equal to its own internal impedance. The load impedance consists of the resistance of the matching network R_m plus the input resistance of the transistor R_t. The source impedance that the transistor sees con-

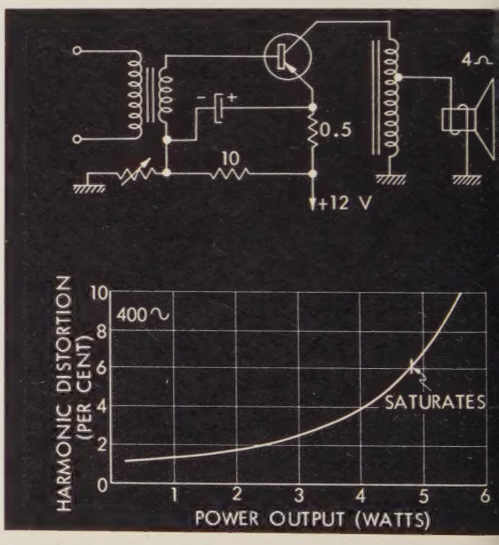


Fig. 9—This single-ended common emitter amplifier stage had a power gain of 38 db. Maximum gain was obtained by bypassing the emitter stabilizing resistor. The transistor load at the primary of the output transformer appears as approximately 11 ohms. The signal source was matched to an input impedance of 8 ohms as measured at the secondary of the input transformer. Power was supplied from a 12-volt source, with the collector current adjusted to one ampere. Output was down 3 db at 4,500 cycles and maximum power output at the clipping point was 4.8 watts.

sists of the network resistance R_m plus the internal impedance R_p of the driver. Thus, the network resistance appears as part of both the load and source, so it should be held to the minimum practical value to keep from upsetting the match and to reduce losses. Except when R_m equals zero, an exact match in both directions cannot be obtained.

With a pentode type driver, the internal impedance R_p is generally much higher than the load impedance. This leaves only the problem of matching the source impedance to the input resistance R_t of the transistor. The simplest way to do this is to parallel a resistance across the transistor input. Since the internal impedance is high for pentode type devices, the sum of the internal impedance R_p and the network resistance R_m is much greater than the shunt resistance R_s. By making R_s equal R_t, the transistor will see its own impedance looking back into the source. With this arrangement, half of the power from the driver is lost in R_s, the shunt resistance—a loss of three decibels in this case.

To obtain linear operation for low distortion with the common collector connection, a source impedance lower than the input resistance can be used. This method of shunt resistance is valuable in obtaining such low impedance sources since the shunt resistance R_s can be made smaller than the input resistance of the transistor R_t by any desired ratio. Additional loss of power is the price. This can be done with either pentode or triode type drivers.

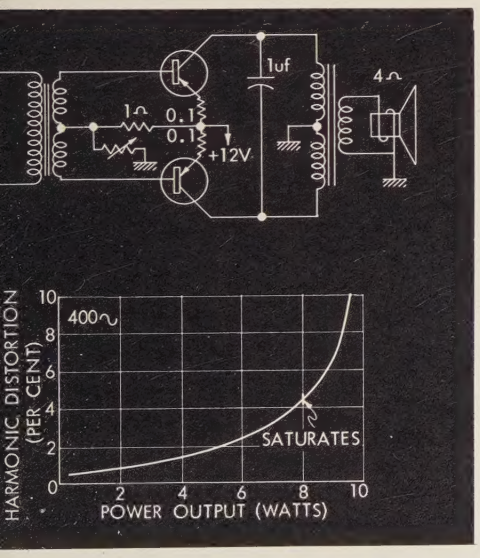


Fig. 10—The power gain of this Class B push-pull amplifier stage in the common emitter connection measured 31 db. A load impedance, collector to collector, of 25 ohms was required. The source was matched to the input impedance which measured 130 ohms base to base. The no-signal collector current was adjusted to 130 ma to obtain minimum crossover distortion at the one-watt level. A 12-volt power source was used. The maximum power output at clipping was 8 watts at 400 cycles, with output down 3 db at 7,000 cycles.

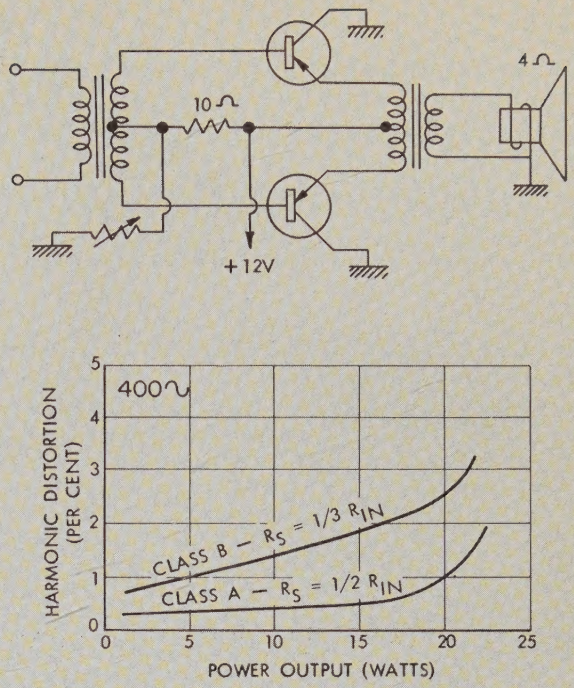


Fig. 11—This common collector, push-pull amplifier had a power gain of 16.5 db in both Class A and Class B operation. Over 20 watts of power output was obtained at the clipping level with an 8-ohm load. A 250-ohm source was used to drive the input impedance, base to base, of 510 ohms in Class A operation and 750 ohms in Class B. A 12-volt power supply was used. Minimum crossover distortion in Class B was obtained with a no-signal collector current of 32 ma (both transistors). In Class A operation, the total power supply current required was 4 amperes.

For the common base circuit it is desirable to have a high impedance (current) source. Leaving out the shunt resistance R_s will accomplish this. For the triode driver, series resistance should be added which makes the circuit similar to the one shown in Fig. 8. When designing such a circuit, however, one possible danger must be considered. If the added resistance increases the d-c total in the base circuit of the transistor, temperature stabilization of the circuit may be affected sufficiently to require a review of the temperature problems.

Circuit Data and Performance Summarized

Three transistor amplifiers and their performance characteristics show typical results that may be obtained with transistor amplifiers in various applications (Figs. 9, 10, 11).

In this paper, emphasis has been placed upon the available method of reducing or obtaining minimum distortion in the various configurations. Depending upon the application, however, it may not be necessary to use these special methods to obtain acceptable distortion levels. In the Delco Radio studies, examples of simple, straightforward circuits were used (Figs. 9 and 10). The resulting distortions were about equivalent to or less than comparable vacuum tube circuits for the same power outputs. Another circuit was developed using the appropriate connections and matching conditions to obtain very low distortion for high power, audio applications (Fig. 11). If special applications require further improvement in performance, more complex circuits with more stages using negative feedback are still available to the designer.

In all the data taken, a 12-volt power supply was used because this is the most common battery voltage used in automobiles. There is no reason why higher voltages cannot be used, if available, except that the transistor voltage limits must be observed.

Bibliography

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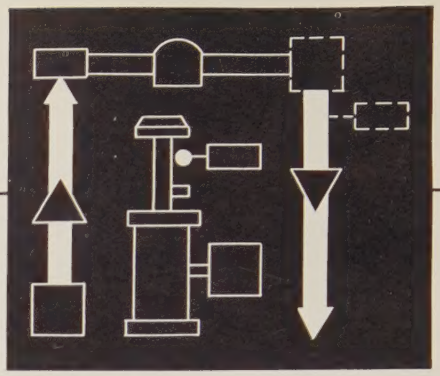
Schwarz, B. A., "A Survey of the Transistor," *General Motors Engineering Journal*, Vol. 2, No. 1 (January-February 1955), pp. 40-7.

A Simplified Method for Showing the Operating Sequence of Complex Manufacturing Equipment



Machine down time due to component malfunction must be minimized if efficient and uninterrupted production is to be realized. This requires that trouble shooting be performed quickly and easily. For this to be done, complete information describing both the machine and electrical sequence of operation must be available. With complex machines, this information should be presented as simply as possible so that the source of malfunction can be easily found by maintenance personnel who may not be completely familiar with the machine. To facilitate trouble shooting on complex manufacturing equipment, engineers of the GM Process Development Staff developed a new and simplified method for presenting the machine and electrical sequence of operation. The new method, based on using symbols to describe machine motions and sequence of operation, is presented in such a manner that the source of malfunction is quickly pinpointed. The method not only helps in reducing down time but also serves as an aid in training machine operators and maintenance personnel.

In recent years technological developments have resulted in increasingly complex machine tools and manufacturing equipment. Typical of these developments are automatic feeding devices; hydraulic, electrical, or pneumatic actuators; feedback control; and sensitive electronic gaging, inspection and control devices. Each of these has contributed to improvements in efficiency in production processes.

Along with the improvements, however, has come the problem of greater difficulty in trouble shooting when a malfunction occurs in the complex machine. Prolonged down time due to component malfunction is a costly item. Thus, ease of trouble shooting is one prerequisite in planning today's plant operation for efficient production.

Symbols Define Machine Motion and Sequence of Operation

The GM Process Development Staff has designed, developed, and built complex equipment of the type described above to meet the specialized requirements of some GM Divisions. Included in this development is the customary preparation of information describing the electrical sequence of operation and the mechanical operation of a machine. Such information is provided for trouble shooting.

The ease with which a person can trouble shoot a machine depends upon such factors as familiarity with the machine, the manner in which the elementary electrical diagram is drawn, the amount of supplementary information available, the complexity of the machine,

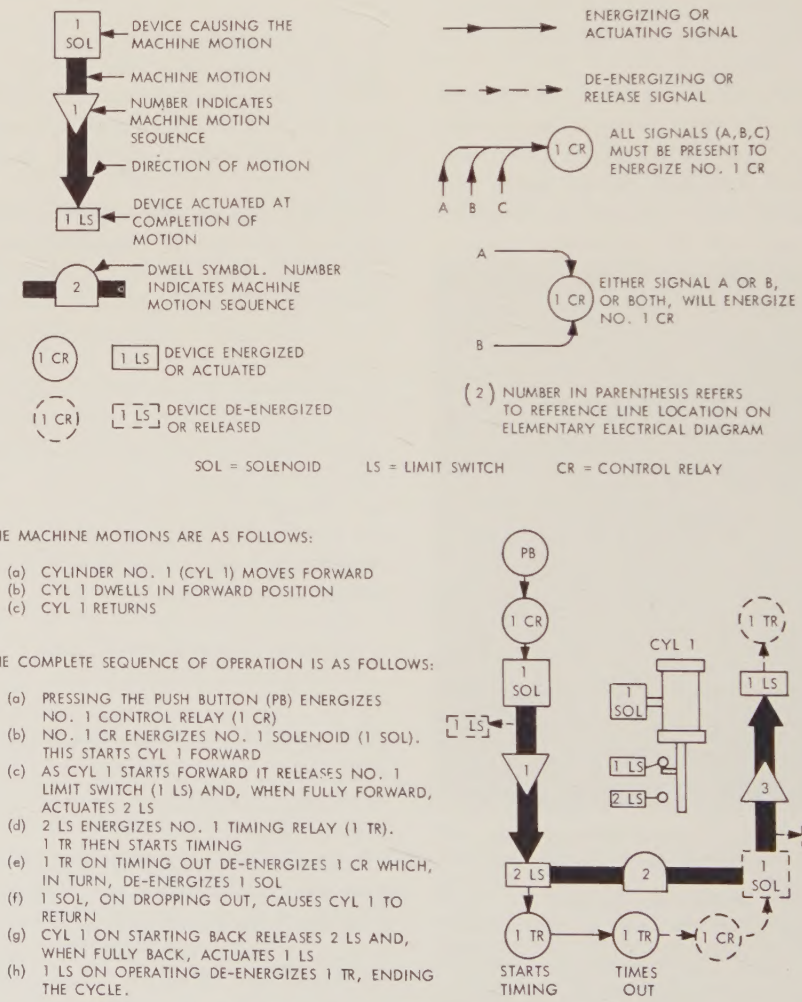


Fig. 1—The symbols used in the simplified method for illustrating the sequence of machine operation are shown at the top. An example illustrating the application of the symbols to describe typical machine motions and sequence of operation is shown at the bottom.

By JOHN E. CRAIG
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Process Development Staff

Trouble shooting simplified

and the clarity of the sequence of machine operation.

The electrical sequence of operation includes an elementary electrical diagram showing the operation of the electrical circuits by a scheme using electrical symbols. Usually, a written sequence of mechanical operation is supplied and, for a large machine, is presented in booklet form. The size of the booklet depends on the complexity of the machine.

This method of presenting the electrical and mechanical sequence of operation has, in the past, provided the required information. It has not, however, served as a quick reference for trouble shooting in cases of equipment malfunction. It was felt, therefore, that a simpler and better way of presenting the sequence of operation was needed.

As a result, engineers of the Process Development Section of the GM Process Development Staff undertook a project to find a simple yet effective method for representing the sequence of operation. The objective was to develop a method which would permit easy understanding of the machine operation by electricians and other maintenance personnel, and also serve as a quick reference for trouble shooting, thereby achieving the goal of minimum down time.

One of the major problems involved was the development of a method using a suitable set of symbols for describing as simply as possible the machine motions and sequence of operation. Various methods were developed, tried out, and then refined until a final set of symbols was agreed upon (Fig. 1). The method was found to be adaptable to machines operated by either hydraulic, pneumatic, or electrical controls.

One type of machine to which the simplified method was applied is a vane loading machine which loads vanes automatically into transmission torus assemblies (Fig. 2).

When applying the simplified method to trouble shooting, an elementary electrical diagram (Fig. 3-left) of the machine is used in conjunction with the sequence of operation diagram (Fig. 3-right).

Summary

It is estimated that in the average case of trouble shooting, knowing how the

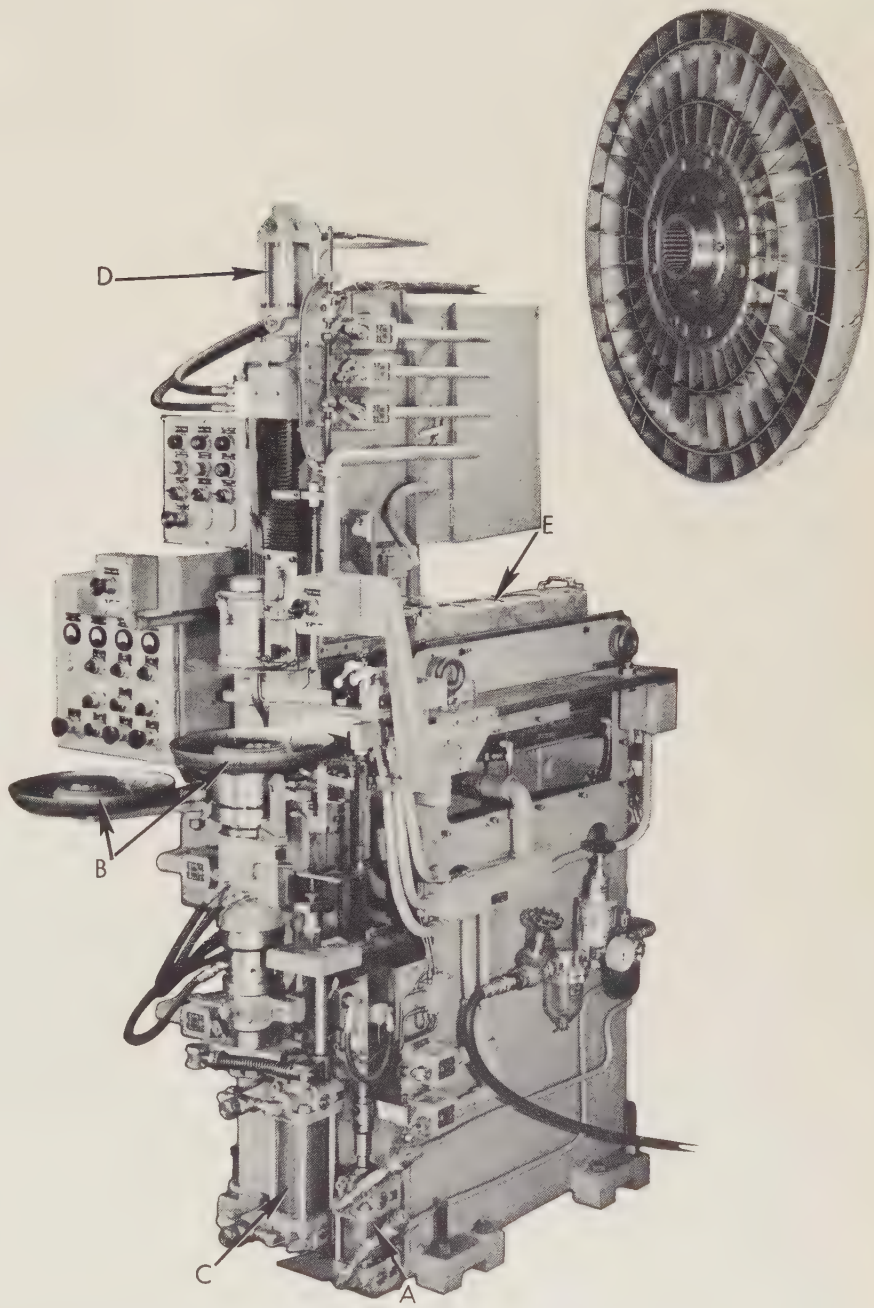
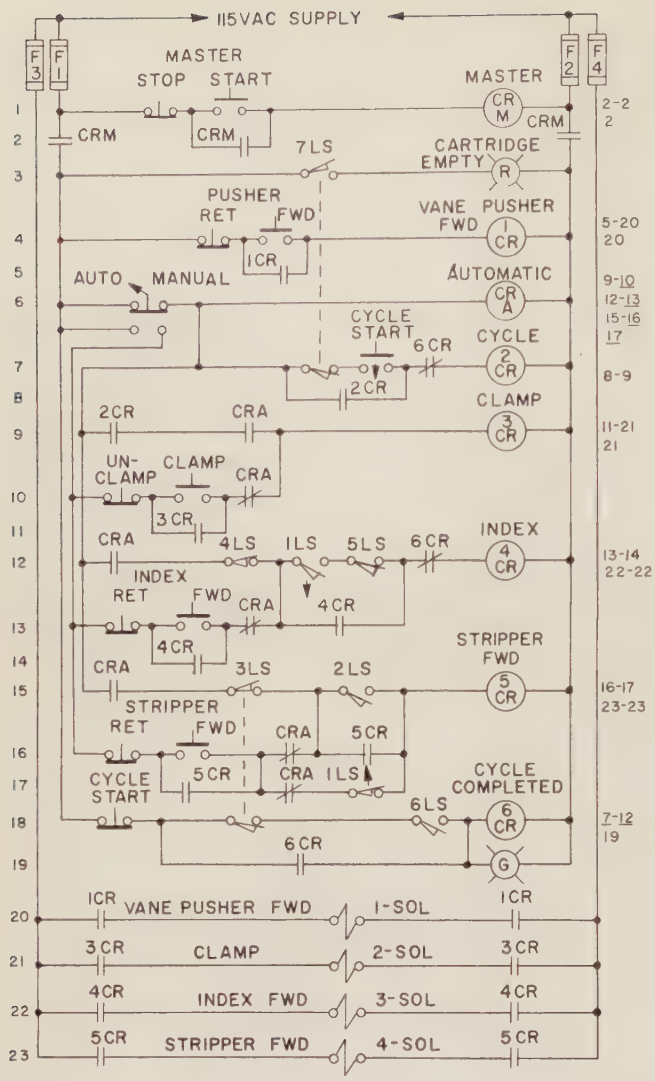


Fig. 2—Shown here is a vane loading machine designed, developed, and built by the GM Process Development Staff to load vanes into automatic transmission torus assemblies (insert). This machine is similar in operation to the vane loading machine for which the elementary electrical and sequence of operation diagrams shown in Fig. 3 were prepared. The primary difference is that for this machine the index cylinder *A* is mounted vertically, as compared to a horizontal position for the machine described in Fig. 3. Also, this machine was developed to load 36 vanes into the torus shell *B*, as compared to 24 equally spaced vanes. Other major components of the vane loading machine are the clamp cylinder *C*, stripper cylinder *D*, and magazine *E* for the vanes.



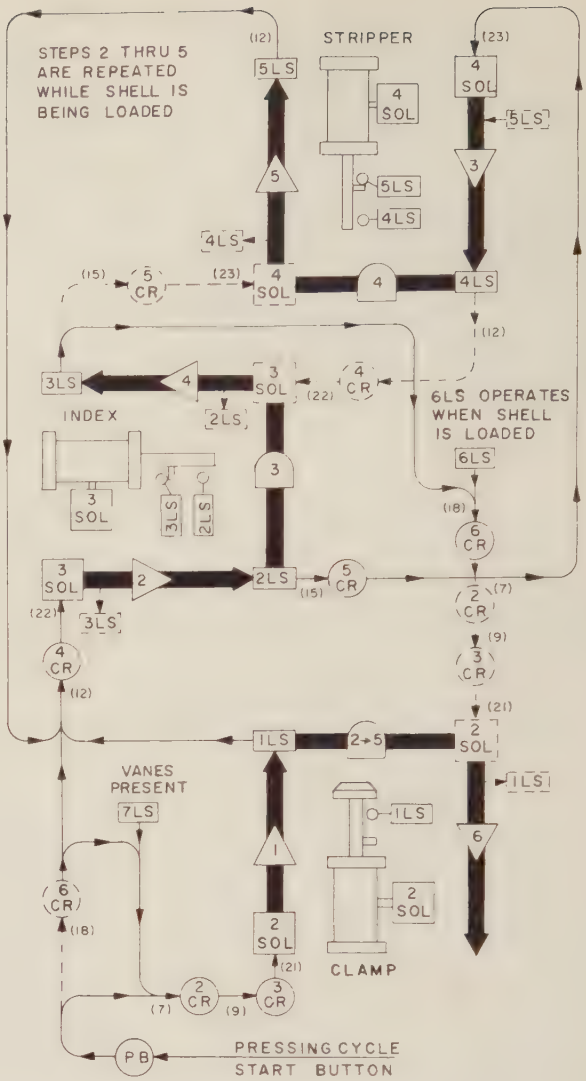


Fig. 3—The simplified method for presenting the electrical sequence of operation (left) and machine sequence of operation (right) is based on using a pictorial representation to show the overall machine motions. The sequence of operation depicted at the right is for a vane loading machine (similar to that shown in Fig. 2) in which 24 vanes are inserted into an automatic transmission torus shell having equally spaced radial slots.

The sequence of operation is as follows. After loading an empty torus shell into the machine, the operator presses the start cycle button. This starts the loading cycle. The clamp cylinder raises the empty shell to the loading position and clamps the shell. The index cylinder indexes the shell (against a positive stop) into position. The stripper cylinder then strips a vane from a magazine and inserts it into a slot in the shell. The stripper cylinder remains in the lowered position while the index cylinder returns. When the index cylinder is fully returned, the stripper cylinder returns and a new index operation is started. The index cylinder and stripper cylinder repeat the same sequence until the shell is loaded. When the shell is loaded, a limit switch is actuated and the stripper cylinder and clamp cylinder are returned together, ending the cycle.

To illustrate how the simplified method for presenting the machine sequence of operation aids in trouble shooting, assume that the shell is clamped and that the index cylinder is in a forward position. It is at this point that a malfunction occurs, stopping the machine. On analyzing the machine motion it is found that the sequence of operation diagram indicates that the stripper cylinder should have moved forward. A check is then made to see if No. 4 SOL (solenoid) was energized (reference line 23 on the elementary electrical diagram). If 4 SOL was not energized, a check is made to see if No. 5 CR (control relay) was energized (reference line 15). If 5 CR was not energized, a check is then made to see if No. 2LS (limit switch) was actuated. By such a process, therefore, the source of the malfunction can be found quickly with a minimum of machine down time.

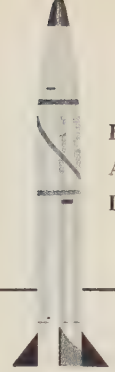
machine is supposed to operate is 50 per cent of the job, being able to find the source of trouble is 25 per cent of the job, and correcting the source of trouble is the remaining 25 per cent. Based on this estimation, the simplified method takes care of 75 per cent of the average case of trouble shooting. The pictorial form of presentation allows the overall sequence of machine operation to be easily understood. As a result, trouble spots are quickly and easily pinpointed.

The simplified method for presenting the mechanical operation and the electrical sequence of operation is presently being applied in some GM manufacturing Divisions.

Acknowledgement

The author acknowledges the suggestions made by Messrs. J. F. Salatin, W. L. Hostetler, and D. Ward of Delco-Remy Division to improve the method during its development.

Data Reduction Facility Provides Information to Evaluate Missile Performance Tests



By JACK W. BECKER
AC Spark Plug
Division

Electronic equipment processes inertial guidance system test data

In the development of operational missiles for the national defense program, obtaining accurate data of actual or simulated performance is necessary to evaluate and improve missile design and reliability. After the data are obtained from the test, they must be translated, or reduced, to a form which enables engineers to evaluate the test performance. One of the tools used to translate missile systems performance data is the data reduction facility operated by AC Spark Plug Division in Milwaukee. Here, data from test sites across the nation are reduced and evaluated to provide missile engineers with a true measure of their product.

In the research and development phase of a missile program, large amounts of telemetered data are collected from field test sites. These data, when reduced, give an evaluation of the missile system performance under actual or simulated operating conditions. The reduction of the telemetered data involves a great amount of electronic equipment. While most of this equipment has been developed only within the past five years, it is now standard equipment in any aircraft or missile telemetry data reduction system.

Such a data reduction facility is located at the Milwaukee plant of AC Spark Plug Division. This data reduction station was established as an Air Force facility for the reduction of inertial guidance system data from Thor missile test programs. Input to the station is data contained on magnetic tapes recorded at: the missile launching site at Cape Canaveral, Florida; the Supersonic Naval Ordnance Research Track at China Lake, California; and the Missile Static Test Site at Edwards Air Force Base, California.

As many as 76 signals which monitor guidance system parameters are contained on one tape for a test. At the data reduction facility, these multiplexed signals are separated and either graphed for visual read-out or digitized for input to a digital computer. All data eventually go to an engineering data analysis section for test evaluation.

Data Gathering Comprised of Three Phases

The first step in the process of data reduction is to collect the data in a form

SUBCARRIER BANDS

BAND	CENTER FREQUENCY (CPS)	LOWER LIMIT (CPS)	UPPER LIMIT (CPS)	MAXIMUM DEVIATION (PER CENT)	FREQUENCY RESPONSE* (CPS)
1	400	370	430	±7.5	6.0
2	560	518	602	±7.5	8.4
3	730	675	785	±7.5	11.0
4	960	888	1,032	±7.5	14.0
5	1,300	1,200	1,398	±7.5	20.0
6	1,700	1,572	1,828	±7.5	25.0
7	2,300	2,127	2,473	±7.5	35.0
8	3,000	2,775	3,225	±7.5	45.0
9	3,900	3,607	4,193	±7.5	59.0
10	5,400	4,995	5,805	±7.5	81.0
11	7,350	6,799	7,901	±7.5	110.0
12	10,500	9,712	11,288	±7.5	160.0
13	14,500	13,412	15,588	±7.5	220.0
14	22,000	20,350	23,650	±7.5	330.0
15	30,000	27,750	32,350	±7.5	450.0
16	40,000	37,000	43,000	±7.5	600.0
17	52,500	48,560	56,440	±7.5	790.0
18	70,000	64,750	75,250	±7.5	1,050.0
A**	22,000	18,700	25,800	±15.0	660.0
B	30,000	25,500	34,500	±15.0	900.0
C	40,000	34,000	46,000	±15.0	1,200.0
D	52,500	44,620	60,380	±15.0	1,600.0
E	70,000	59,500	80,500	±15.0	2,100.0

*Frequency response given is based on maximum deviation and a deviation ratio of five

**Bands A through E are optional and may be used by omitting adjacent bands as follows:

BAND USED	OMIT BANDS
A	15 and B
B	14, 16, A, and C
C	15, 17, B, and D
D	16, 18, C, and E
E	17 and D

Table I—Eighteen subcarrier bands are used in the FM telemetering system for gathering data. Normal deviation is 7-1/2 per cent with a 15 per cent deviation possible on the higher channels, as indicated by Bands *A*, *B*, *C*, *D*, and *E*.

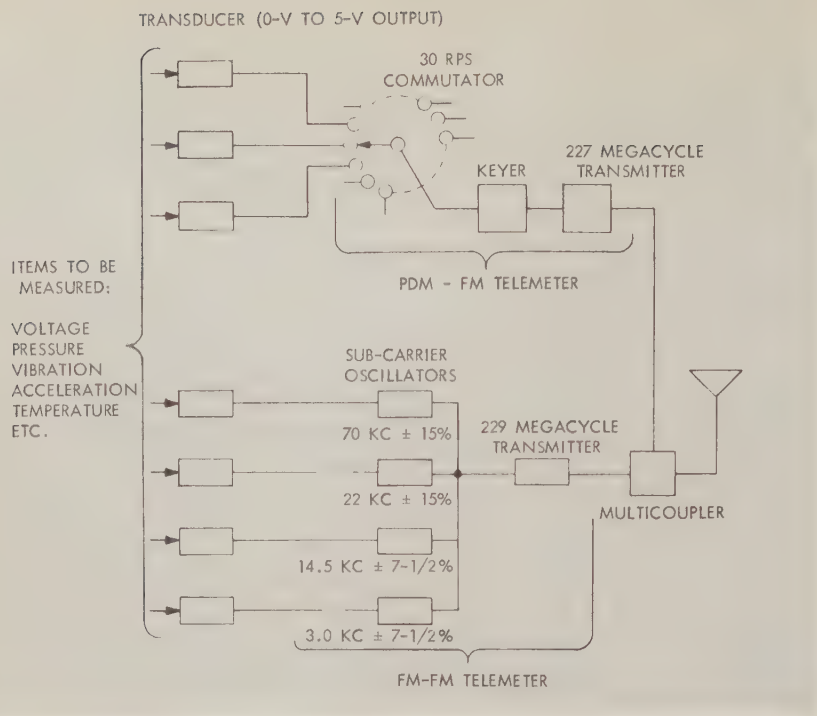


Fig. 1—Typical airborne PDM and FM telemeters are depicted by this block diagram. Transducers provide the input to the telemeters, which accept the information, place it in transmittable form, and transmit it to the ground.

suitable for reduction. The equipment used to accomplish this is called the data gathering system. This varies somewhat at each test site, but all systems basically consist of transducers or pickups, a multiplexing and modulation unit, the transmission link, and the recording device. In some cases, all of these items as a group are termed a telemeter. In this paper, only the multiplexer, modulator, and transmitter components are considered to constitute a telemeter. The three components of the data gathering system are the transducer, telemeter, and recorder.

Transducers

The transducer, or pickup, is any device which converts the item to be measured into a voltage form suitable for input to the telemeter. In most cases, this input is restricted to a voltage range of from zero to plus five volts. Typical transducers are pressure, vibration, linear or angular acceleration and temperature pickups, voltage dividers, voltage comparators, metering resistors, and a-c voltage demodulators.

Telemeters and Recorders

Two kinds of telemeters are used by AC Spark Plug. One is a frequency modulation *FM* and the other a pulse duration modulation *PDM* telemeter (Fig. 1).

In the FM telemeter, the transducer outputs are applied as inputs to voltage-controlled subcarrier oscillators, whose frequency varies with the voltage input. There are 18 subcarrier oscillator center frequencies, as standardized by the Inter-Range Instrumentation Group *IRIG*. These frequencies range from 400 cps to 70 kc. Normal deviation is seven and one-half per cent, with 15 per cent deviation possible on the higher channels. Recommended maximum information

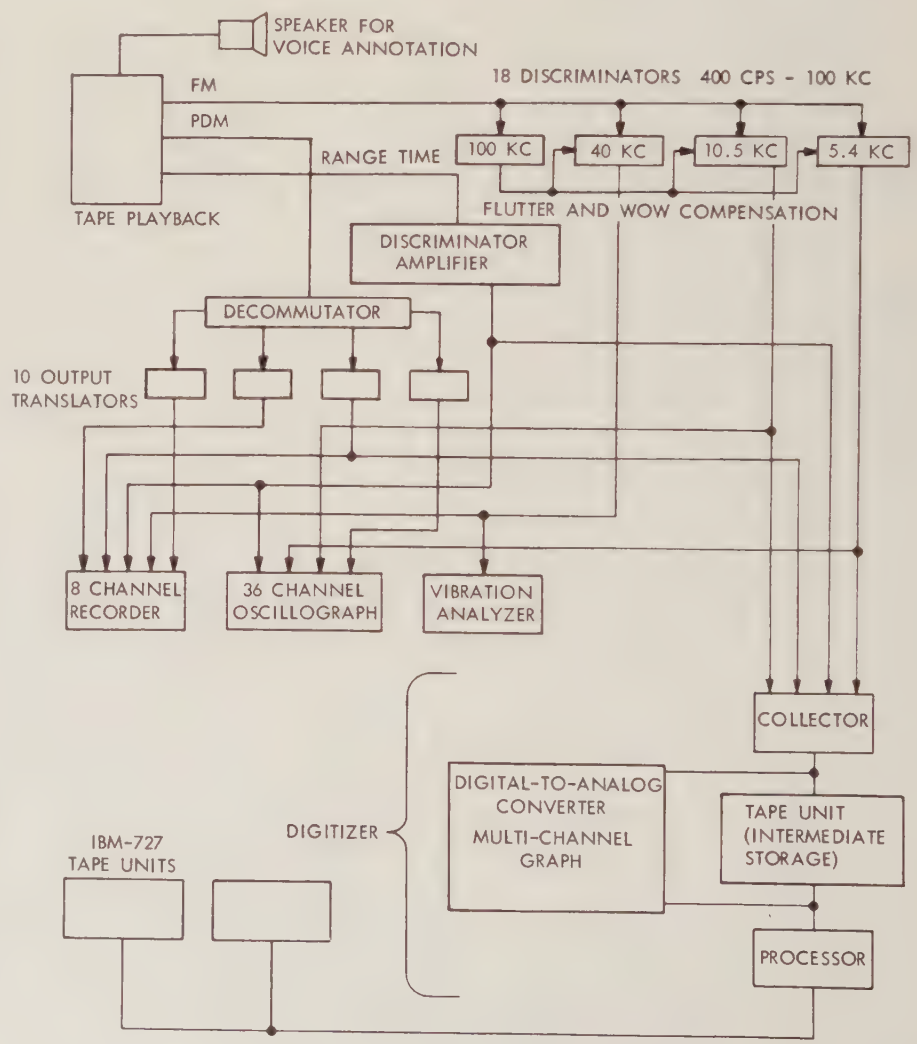
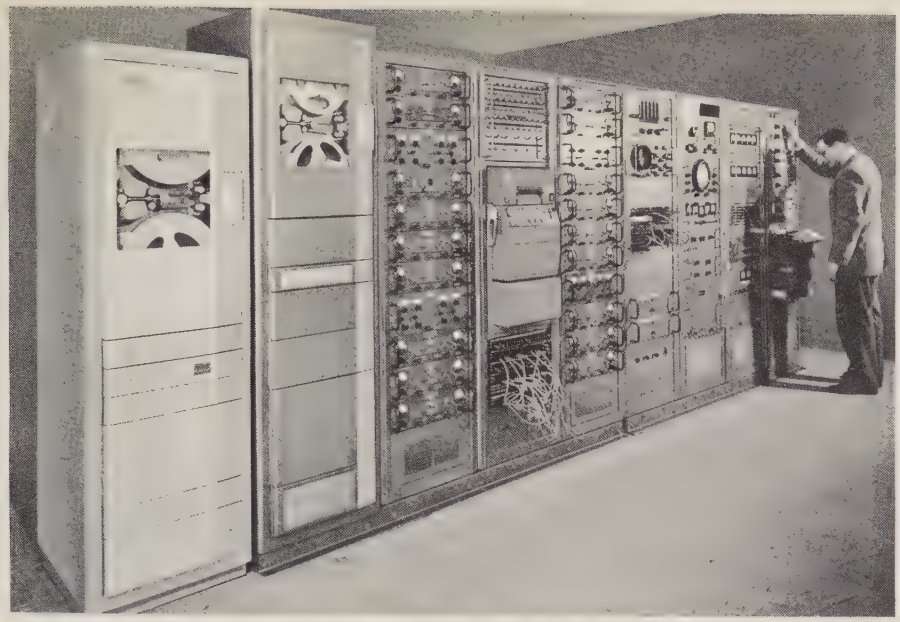


Fig. 2—This block diagram represents the principal components of the data reduction facility at AC Spark Plug Division's Milwaukee plant. Inputs to the system are the magnetic tapes containing FM and PDM data recorded at the field test sites. The data can be written on oscillographs or direct-writing multichannel recorders. Data also can be fed to the digitizer which translates the information into binary coded decimal data suitable for input to an electronic computer. Vibration data can be fed to the digitizer as well as to a vibration analyzer, which makes graphs showing frequency, time, and *g* level, and to a tape unit, which prepares tapes for analysis in a vibration laboratory.



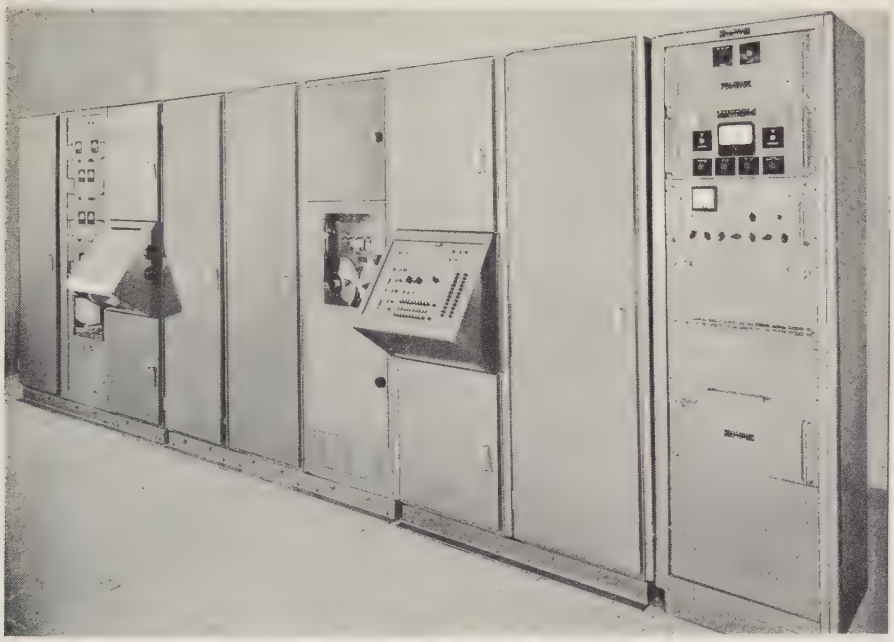


Fig. 3—The physical layout of the data reduction system consists of two facing rows of relay racks. One row is the analog section (top); the second is the digital section (bottom). The analog section includes (from left to right): two tape playback units, two sets of FM discriminators separated by an oscillograph, a test equipment rack, two racks of PDM equipment, and an eight-channel recorder. The digital section (digitizer) prepares data for the electronic computer (Fig. 4). From left to right, the first three racks hold the "quick look" recorder and circuitry. The fourth rack is the collect system, the fifth holds test equipment, and the sixth holds the intermediate recorder. The seventh and eighth racks constitute the processor section. The ninth rack contains the vibration analyzer.

frequency response is 2,100 cps on the 70 kc ± 15 per cent channel.

The oscillator outputs are either mixed and fed to a FM radio transmitter or wired directly to a tape recorder. The FM system permits transmission of signals with a frequency response as high as 2,100 cps, and is limited to a maximum of 18 channels with 12 channels being a more representative number (Table I).

A PDM telemeter is a time multiplexing device which enables transmission of a large number of signals of low frequency. IRIG standard systems used by AC Spark Plug engineers include 30 by 30 and 45 by 20 telemeters. The former measures 30 channels each 30 times per second and the latter measures 45 channels each 20 times per second. Thus, PDM telemeters are limited to signals with a maximum frequency of about five cps. Each channel is sampled by a mechanical commutator, whose output is fed to a keyer which transforms the pulse amplitude into a pulse width. The output of the keyer either modulates an FM transmitter or is wired directly to a tape recorder.

The frequency range in radio telemetry is from 215 mc to 240 mc. Transmitters must be crystal controlled and deviations of ±100 kc for PDM and ±125 kc for FM are common. The receiver output is coupled directly to a multitrack magnetic tape recorder. Each telemeter is recorded on a separate track, and voice annotation and timing signals are placed on other tracks.

After the data are gathered in suitable form, the information is supplied to the data reduction facility.

Several Components Form Data Reduction Facility

The facility at AC Spark Plug can handle FM or PDM telemetered data received from the test sites and recorded on magnetic tapes (Fig. 2). The equipment separates the frequency or time multiplexed channels, discriminates or decodes the data, and either records it on a visual chart or enters it into a digitizer. The digitizer converts the analog signals into another magnetic tape suitable for input to an electronic computer.

Tape Playback Units

Input to the facility can be on one-half in. magnetic tape with seven or four tracks, or on one-in. tape with 14 tracks. Reels can be either 14-in. or 10½-in. diameter. Tape speeds of 60, 30, 15, 7½, 3¾, and 1⅞ in. per sec are available. A servo speed control system can use either a 17-kc or an 18.24-kc taped carrier signal to compensate for tape stretch or contraction. The outputs of up to three FM telemeters and two PDM telemeters can be played back at one time.

FM Station

The FM station can discriminate 18 channels selected from three different telemeters at one time. All standard IRIG channels can be handled as well as 54 kc ±40 per cent deviation. A tape speed compensation system utilizes a 100-kc precision frequency from the test tape to adjust the discriminators for flutter and wow in the tape record and playback systems. An automatic discriminator calibration system also is available for use

with special coded calibration signals recorded prior to the test.

PDM Station

The PDM station can decommutate either 30 by 30 or 45 by 20 PDM signals. Automatic zero and full scale compensation can be secured either from voltages recorded on the tape or from the ground station itself. Subcommutated signals at rates of six or 1½ samples per sec can be decommutated. A maximum of 10 signals from one telemeter can be graphed or digitized at one time.

Graphical Recorder

The graphical data outputs are written on oscillographs or direct writing multichannel recorders. A practical maximum of 12 signals can be written on a 12-in. oscillogram, although a total of 36 galvanometers are available. Eight channels can be written simultaneously on the direct writing recorder. Maximum frequency response on oscillograph channels is about 3,000 cps, and on the direct writing recorder about 60 cps.

Digitizer

The digitizer accepts inputs from either the FM or PDM stations. A maximum of 22 channels may be digitized simultaneously at 1,000 samples per sec *sps*. Each sample is time identified in seconds and milliseconds. It is possible to use only every tenth or hundredth sample, so that 100 sps and 10 sps also are available. The digitizer also is capable of combining channels so that by connecting all inputs together one signal can be digitized at 22,000 sps.

Each sample of the analog voltage is digitized into a 10-bit binary code which is converted to binary coded decimal *BCD*. An input voltage of −5.12 v converts to a count of zero, and a voltage of +5.12 v converts to a count of 1,023. A signal source from 0 to 30 v can be converted by the station to the ±5.12 v. All values above 999 read out as 999 after conversion to BCD. Output of the digitizer is the binary coded decimal data written on a magnetic tape unit and suitable for input to an electronic computer.

A digital-to-analog read-out device is used to graph the binary coded digitized data. These graphs give a quick check of the digitization process and are used to correlate range time and digitizer time to the millisecond. A programmer searches out and processes only those periods of digitized data that have been selected.

Fig. 4—Final step in the data reduction system is the input to an electronic computer. This facility is located adjacent to the data reduction equipment. An operator is shown seated at the control console of the computer with a read-punch unit at his right. The two tape machines at the extreme right are wired to both the computer and the digitizer.

One tape contains only 23 seconds of real time data when 1,000 samples per second are taken. At 100 and 10 sps, 230 and 2,300 sec of data can be put on one tape. Thus, five minutes of test data, when digitized at 1,000 sps, will require the making of 13 tapes. Switching between two tape units is accomplished automatically.

The time required to process the digitized data is about 18 times longer than real time. That is, one minute of test data requires 18 minutes of digitizer time for actual coding and processing.

Vibration Data Handling Equipment

Three methods may be used to present telemetered vibration data. The first method utilizes a vibration analyzer, which makes three dimensional graphs indicating frequency, time, and *g* level. The second method uses two tape machines to construct a six-ft loop of tape. This loop is sent to the AC Spark Plug vibration laboratory, where it is played back and a graphical display of *g* level versus frequency is made automatically. The third method uses the digitizer and the analysis is done by the digital computer.

Physical Layout

The telemetered data reduction facility described consists of 18 relay racks, each 2 ft by 2 ft by 7 ft, which are arranged in two parallel and facing rows (Fig. 3). This equipment is located in an air conditioned area adjacent to the electronic computer (Fig. 4). It is wired directly to two of the tape mechanisms associated with the computer.

One rack contains a patch panel which allows flexible interconnection of the various facility components, and also the test equipment for alignment and calibration of the system. Test equipment includes a VTVM, oscilloscopes, audio oscillator, EPUT meter, and a digital voltmeter.

Expansion of this data reduction facility has been undertaken which ultimately will provide equipment to allow playback of two PDM telemeters simultaneously, and to present 25 outputs instead of the present 10. Another bank of discriminators will increase the playback capabilities of the FM station. An additional eight-channel, direct-writing recorder and a direct-writing oscillograph will double the graphical output capabilities of the station.

Summary

The AC Spark Plug data reduction facility represents an example of the application of recently developed electronic equipment. Data, supplied on magnetic tapes from various United States missile test sites, is received, reduced, and presented in graphical from or digitized. The system handles large amounts of data accurately and quickly to aid engineers in the analyisis of performance tests of inertial guidance systems.

New Current Analyzer Determines Resistance Welder Performance

By MILLARD A. FERGUSON
General Motors
Process Development Staff

Greater assurance of producing high quality resistance welds is provided by the use of welding schedules. These schedules specify the optimum weld current, time, electrode force, and electrode tip configuration for a given welding machine job. However, trained personnel are needed along with complicated measuring equipment and a considerable amount of time in order to apply the welding schedules. To eliminate these requirements, GM Process Development Staff engineers developed a new meter for measuring weld current and time that is easy to operate and allows welding schedules to be easily applied.

Welding current and time measured by versatile meter

THE volume production of quality spot welds and projection welds in a manufacturing plant requires the proper control of the variables regulated by the welding machine, namely, current, time of current, flow, and electrode force[1].

Assuming a constant electrode force, a weld can be made with a large number of combinations of current and time values. However, for a given weld, there is one combination of current and time which is better than any other. This particular combination results in an optimum condition where there is no excessive material indentation and no expulsion of metal (Fig. 1).

In an effort to insure that welds are made at optimum conditions, *welding schedules* have been developed by the American Welding Society and various other groups. Welding schedules are listings of the optimum weld current, weld time, electrode force, and electrode tip shape for correct joining of a specified combination of metal compositions and thicknesses. This information is intended not only to help produce better and more uniform welds, but also to help reduce welding machine set-up time by telling the set-up man how to make a given weld.

The use of welding schedules in the plant, however, has been a complicated matter due to the instrumentation required (Fig. 2). For example, not every plant has the technically trained personnel to operate the numerous pieces of equipment needed to measure weld current, time, and electrode force. Other plants may not have such equipment available. Still other plants might have both the personnel and the equipment but lack time for the lengthy job of setting up welding machines to conform to a welding schedule.

Seeking to eliminate these problems and to facilitate the use of welding schedules to improve weld quality, Process Development Staff engineers considered the design of a new meter for measuring weld current and time. The following objectives were established for the new meter:

- Non-technical personnel should be able to operate it
- The installation of the meter on the welding machine should be quick and simple using a more versatile pickup device than the conventional air-core toroid
- The meter should be portable and operate from a 110-volt a-c source
- Phase-shifted as well as sinusoidal currents should be measured in terms of rms values
- Weld time should be measured in cycles
- The meter should have no loading effect on the welding machine being measured
- The meter should measure currents of short duration
- Weld currents and times should be held long enough to permit easy reading
- The meter should measure welding machine primary currents, using a current transformer as the pickup device
- Provision should be made in the meter to permit primary and secondary current waveshapes to be monitored on an oscilloscope, or an amplifier and recorder combination
- The meter should be self-checking, if possible.

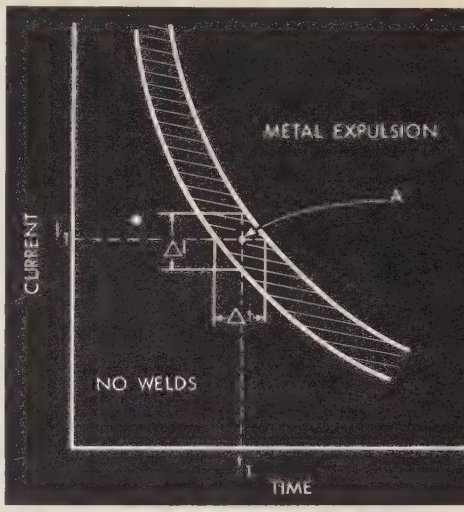


Fig. 1—With other variables held constant, a large number of combinations of current and time exist at which a resistance weld can be made. For a given weld and a particular metal, however, there is an optimum combination of current and time at which the best weld is produced. This graph shows the comparison of welding current and time for a hypothetical welding application. The hatched area is the *welding zone*, or the zone in which welding occurs. The optimum welding point for the given metal is *A*. At the optimum point, permissible variations in current and time exist, ΔI and Δt, which will retain the optimum condition and produce a satisfactory weld. If the welding current becomes greater than the permissible value (falling outside of the welding zone), there is expulsion of metal and indentation of material. If the current becomes less than the permissible value, the metal will not weld. Similar results occur if the weld time is too long or too short, respectively. For some materials, such as mild steel, ΔI and Δt can be relatively large. Experienced welding machine set-up men can set up the machine to weld mild steel by taking advantage of the width of the welding zone.

In developing the new meter to meet the established objectives, the advantages of previous meters and devices were combined and improved by the addition of new ideas and developments to complete the new instrument, called the *weld current analyzer* (Fig. 3). The new meter is basically a device which receives input from a pickup, modifies the information to render it measurable, then transmits it as output to be observed or recorded.

Three Types of Pickup Used

The weld current analyzer is designed to use any one of three pickups—an air-core toroid, a fork-type toroid, and the secondary of a conventional current transformer (Fig. 4). The toroidal pickups plug into the meter at a connector marked *toroid*, and are used to measure welder secondary currents directly. Heavy binding posts accommodate the secondary of a current transformer when it is desired to measure welder primary currents.

The commercially made air-core toroid pickup has been potted in an epoxy resin for ruggedness. This type of toroidal pickup, made in various sizes, is designed to slip over the electrode or electrode holder in the welder secondary (Fig. 5-top).

The fork-type, or parallel toroid pickup, is a new type developed at Delco Products Division by A. W. Kolb while completing his Fifth-Year Project Study Assignment to obtain his bachelor of mechanical engineering degree from General Motors Institute[2]. It operates on the same principle as a conventional toroid and can be considered as a deformed toroid with sections removed. The removed sections contribute little to the output voltage. This pickup is designed to be used at various places in the welder secondary circuit, and gives excellent results as long as the size of the current carrying member of the welder is not greater than 2.0 in. by 10 in. in cross section (Fig. 5-bottom).

The two different types of toroidal pickups allow the meter to be used with most resistance welding machines even when considerable weld fixturing and production tooling, such as that employed in projection welders, is encountered.

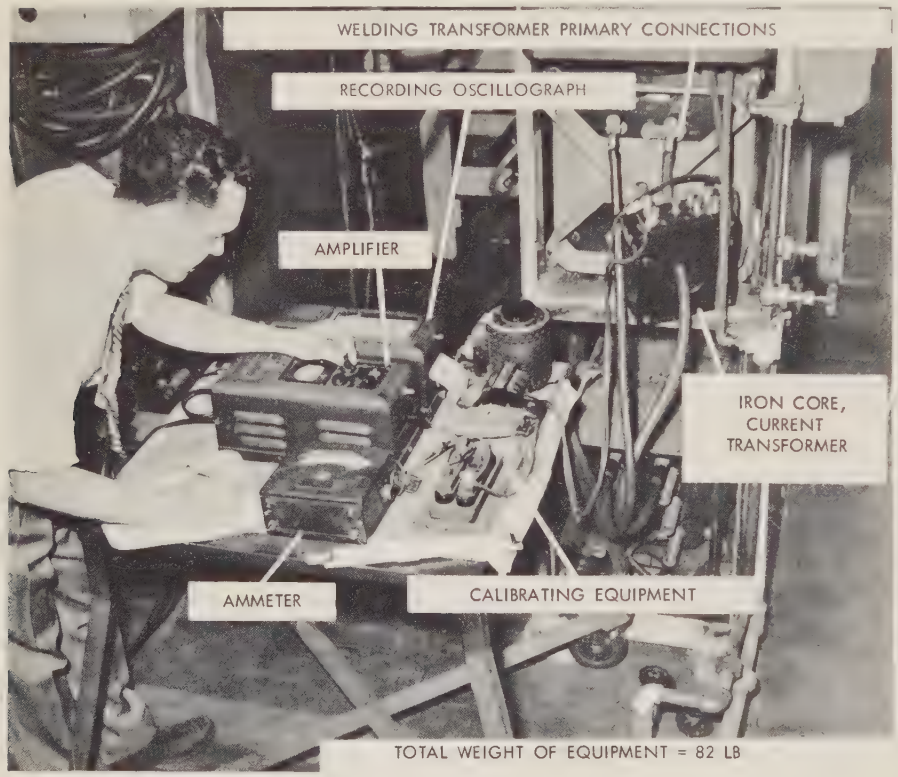


Fig. 2—Some of the problems in applying welding schedules are illustrated in this photograph of conventional current and time measuring equipment. The equipment is bulky, and requires trained personnel and much time to set up. These factors prevent its use in applying welding schedules in many production operations.

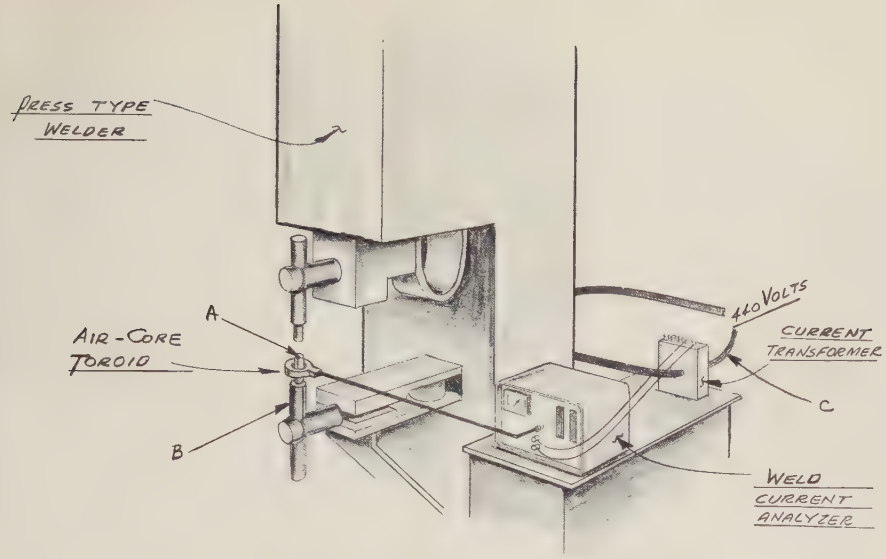
Fig. 3—The weld current analyzer, developed and produced by the GM Process Development Staff, is very compact and easy to use in comparison to former equipment (Fig. 2).

For those welders with a secondary configuration which does not lend itself to use with either of the two toroids, the third pickup, a conventional current transformer, is used to feed the meter, which then behaves like an ammeter (5 amp) with a "memory." That is, the reading is retained long enough for easy reading.

Meter Easy to Operate and Read

A six-position selector matches the meter to the magnitude of the current to

Fig. 4—The three types of pickups designed for use with the weld current analyzer are the air-core toroid *A*, the fork-type toroid *B*, and the conventional current transformer *C*. The two toroidal pickups are used to measure welder secondary current directly, and the current transformer is used to measure welder primary current.



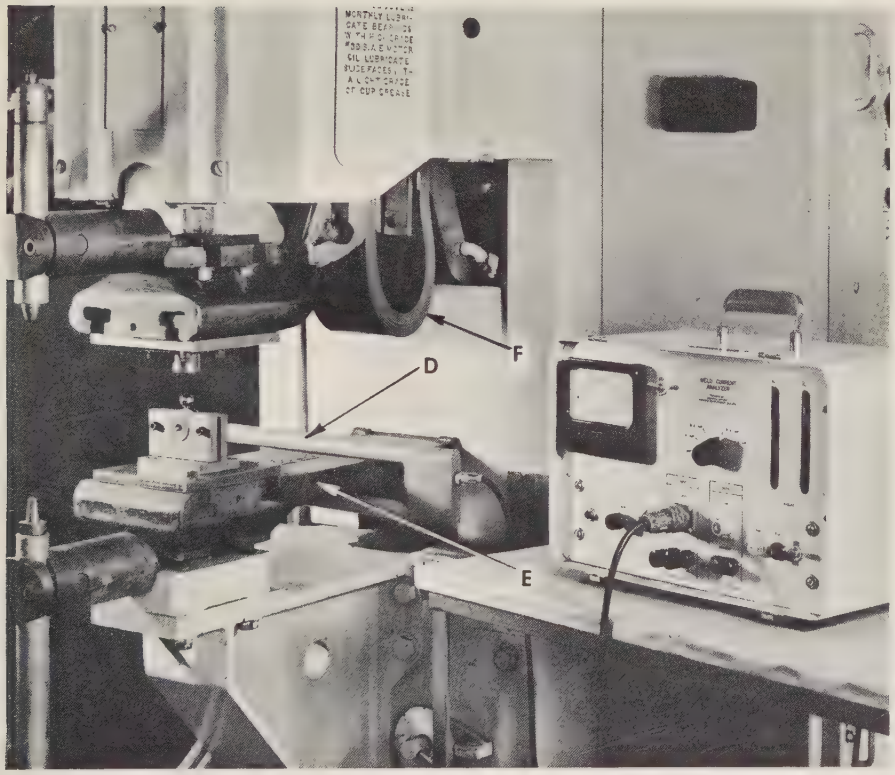


Fig. 5—The sketch of a press type welder (top) shows the application of an air-core toroid, a current transformer, and the weld current analyzer. The air-core toroid is placed over either the electrode *A* or electrode holder *B*, in the welder secondary. The current transformer measures the welder primary by being placed over the primary current bus *C*. In the bottom photograph, the fork toroid *D* is shown being used to measure the secondary current on a press type welder, where fixturing for projection welding is being used. The pickup is shown placed over the casting *E*, but it also could have been used over the flexible jumpers *F* with equal accuracy.

be measured. One position, marked *5 amp*, is used when a current transformer is furnishing the input signal. When using the toroidal type pickups one of the four positions marked *K-amp* (kiloamperes) is used. This switching arrangement permits four overlapping ranges (full scale) of 5, 10, 20, and 40 kilo-amps to be selected. The sixth switch position, marked *cal*, is used to check for proper operation of the meter.

Two electronic counters display the weld time in cycles, up to a maximum count of 99. A *reset* push button is used both to clear the counters and to zero the meter. The exact zeroing of the meter is accomplished with a *zero* control.

Internal Circuitry Modifies Input

In the internal functioning of the meter, the output voltages of either type of toroidal pickup are passed through an attenuating circuit, and are fed into an integrating circuit to obtain a voltage proportional to the welder secondary current (Fig. 6).

It is necessary to integrate the toroidal output voltage because the toroid is an inherent differentiating device. This means that if the toroid is surrounding a conductor carrying a sinusoidal current, then, when the conductor current is at the peak value, the value of the instantaneous voltage at that moment induced in the toroid will be zero, because the rate of change of current at that instant is zero. Later in the cycle, when the conductor current passes through zero, the instantaneous voltage in the toroid will be at the sinusoidal peak because the rate of change of current is at a maximum as it passes through zero.

When only sine waves of current are passing through the conductor, the output of the toroid follows the current waveshape with only a 90° phase shift occurring. However, when phase shift heat control is used to vary the current passing through the center of the toroid, the output voltage of the toroid no longer resembles the original current wave. By integration, a voltage is obtained which is similar in shape to the welder secondary current.

For the true toroid, only the magnetic flux produced by the welder secondary conductor inside the toroid has any effect on the induced voltage. Magnetic flux produced by conductors outside the toroid, even if close by, produces no voltage in the toroid. The effect of adjacent current-carrying conductors on the fork-type pickup is negligible as long as the current-carrying conductors are not located near the open end of the pickup.

The output voltage of the first integrator, which is similar in shape to the welder secondary current, is passed into a squared output circuit. The output from the third means of pickup, the secondary of a current transformer, also is fed into the squared output circuit at

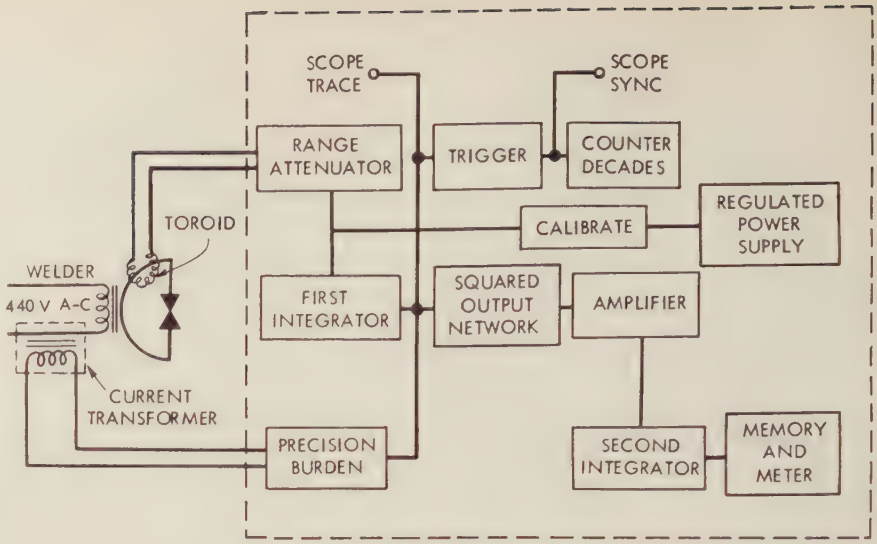


Fig. 6—The internal functioning of the weld current analyzer is illustrated by this block diagram, which shows the application of the meter on a 440-volt a-c welding machine. Both kinds of pickups, toroidal and current transformer, are illustrated, although only one is used in any given application. The pickup delivers input to the meter (enclosed by dotted lines) through one of the two input receptacles, depending upon the kind of pickup used. After modification by the meter circuitry, the information is produced as output at any one of the three points shown on the diagram. The output is delivered for scope trace or memory and meter through the *current* jack of the meter (Fig. 3). It is delivered through the *sync* jack for exact oscilloscope triggering in special cases. The regulated power supply provides a constant current to the *current* jack for calibration purposes.

this point. A precision one-ohm resistor serves both as a burden for the current transformer and as the signal source for the squared output circuit.

The signal coming out of the squared output circuit is a low level signal and must be amplified. After amplification, the signal again is integrated in the second integrator. The peak value of this integration is measured and held in the metering section. The three stages ahead of the metering section are necessary to make measurement of phase-shifted, or phased-back, currents possible. If only sinusoidal waves had to be measured, then only the first integrator and the metering section would be required.

Two Jacks For Output Function

Two jacks are used in connection with the viewing of the waveforms being measured, a *current* jack and a *sync* jack.

The *current* jack provides an output signal to an oscilloscope or an amplifier and recorder. The connector marked *sync* (Fig. 3) is used in the exact triggering of an oscilloscope in special cases, such as those in which it is desired to view or photograph the trace of a one-cycle weld.

The *current* output jack furnishes a signal similar in shape to the welder secondary, when the toroidal pickups are used, and similar in shape to the primary current, when a current transformer is used as a signal source. When the range switch is in the calibrate position *cal*, a regulated 60-cycle signal is supplied to the *current* output jack, forming a convenient means of adjusting either the oscilloscope or the amplifier-recorder combination.

A visual display of the welder secondary current waveform is a most useful tool in the set-up and trouble shooting work of plant welding departments. If a record of a trace is desired, either the oscilloscope camera or an amplifier-recorder can be used. Phase-shifted waves are not revealed in sufficient detail by the recorders generally found in a manufacturing plant; usually the oscilloscope serves better for this purpose.

To obtain a signal to operate the electronic counters, the output of the first integrator is shaped into a square wave by a shaping circuit. The first, or *ones*, counting unit registers one count for every square wave received, and passes a signal to drive the second, or *tens*, counting unit for every ten pulses received. Weld times are counted with absolute accuracy for both phase-shifted and sinusoidal weld currents.

The output of the *sync* jack is used when it is desired to display the current waveform under consideration on an oscilloscope. This output has been found valuable when one- or two-cycle phase-shifted weld currents are being studied. The synchronizing signal from the weld current itself is used to produce consistent, easily photographed, oscilloscope representations.

Summary

The development of the weld current analyzer provides production men with an instrument to easily and speedily measure the effective performance of welding equipment. The new meter utilizes three pickups, which enable measurement to be made of secondary and primary currents of most welding machines used today. The meter itself receives input from the pickup, then modifies it for observation or for recording on an oscilloscope or a recording-amplifier.

The new meter is relatively easy to operate, and its use does not require highly trained personnel. This, plus its portability and versatility, makes it much easier for engineers to apply welding schedules to production work. The use of welding schedules results in better weld quality, consistent welds, fewer rejects, lower costs, and an improved final product.

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Solving Design Problems in a Diesel Powered Generating Plant for Peaking and Reserve Capacity

By B. B. BROWNELL*
Electro-Motive
Division

The idea of a Diesel powered plant for generating electricity is not unusual. The railroad locomotive and the municipal power plant are familiar applications. A less familiar use is a specially designed plant to provide peaking and reserve capacity in the operation of a utility. Such a plant recently was developed by Electro-Motive Division. The peaking and reserve plant presented some design requirements which normally are not a part of Diesel-generator development. Yet these special requirements were met by applying sound engineering fundamentals along with considerations of economy and reliability. Three problems which had to be solved were: turbocharging the engine to increase rated capacity, reducing the overall noise of the plant, and providing a control system to enable the plant to operate unattended with safety and reliability.

Three problems were: turbocharging, sound deadening, and the control system

DESIGNING a Diesel powered generating facility for use by utilities in peaking or reserve applications presented some special problems. Such problems were caused by the requirements which this type of plant was to meet. A discussion of these requirements and the overall development of the peaking and reserve plant appeared in the April-May-June 1959 issue of the JOURNAL[1]. Briefly summarized, these were the design criteria:

(a) *Higher capacity:* minimum capacity should be 5,000 kw
(b) *Lower cost:* the cost per kilowatt of installation and operation should be lowered to make the plant economical for peaking and reserve service in a utility system
(c) *Ease of transportation:* the plant should be of minimum size and weight to facilitate delivery, initial installation, or relocation
(d) *Unattended operation:* functioning of the plant should be automatic, requiring no operator, and should be completely protected for fail-safe operation
(e) *Reliability:* reliable operation should be assured with simplified control system and minimum maintenance requirements
(f) *Quietness:* the plant should be clean, quiet, and presentable—a "good neighbor" in the community
(g) *Fast starting:* the plant must start and be on the line in a minimum of time to fulfill "spinning reserve" needs. (A goal of 90 seconds was selected.)

The resulting design was a generating facility consisting of three, self-contained, enclosed, engine-generator units (rated at 2,000 kw each) and a fourth enclosure housing switchgear and control equipment. The total plant was rated at 6,000-kw output and could be transported and placed on a minimum of 4,000 sq ft of utility property including space for an underground, fuel storage tank.

To satisfy the design criteria, Electro-Motive Division engineers utilized past developmental experience with locomotives and certain smaller mobile generating plants. However, there were some new problems to be solved which were the result of the requirements for peaking and reserve service. Among these problems were: (a) turbocharging and making other mechanical improvements in the Electro-Motive, normally aspirated, Diesel engine in order to increase the capacity, (b) reducing the overall noise level of the complete plant to satisfy the "good neighbor" requirements of the utility, and (c) developing a control system to meet the requirements of unattended operation, fast starting, reliability, fail-safe operation, and economy.

Turbocharging the Engine

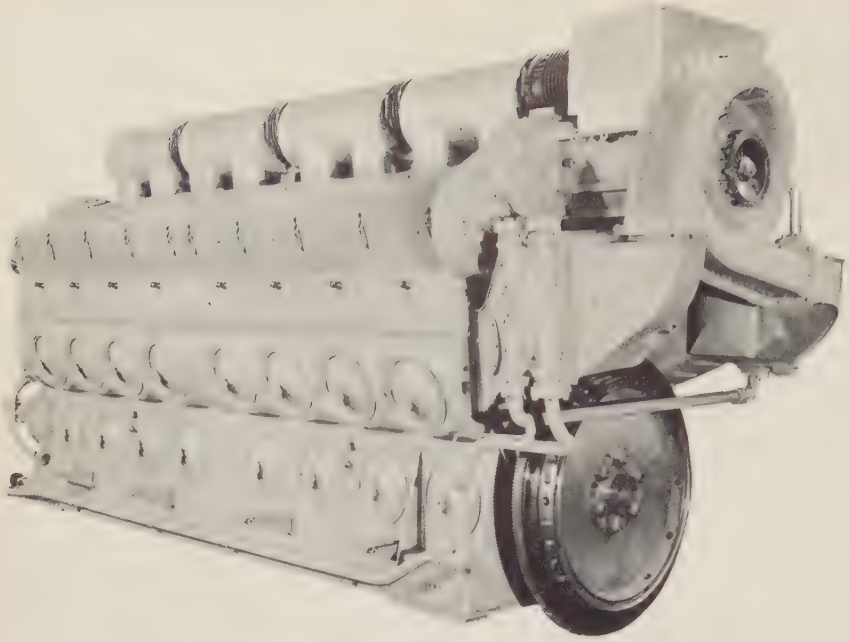
An obvious means of making a substantial reduction in the cost per kw of the 6,000-kw generating plant was to make a substantial increase in the rating of the Diesel engine. In a previous Electro-Motive mobile generating unit, the engine produced an output of 1,000 kw. Doubling this rating to 2,000 kw with a minimum increase in the cost of the engine was set as a design goal.

Turbocharging the 16-cylinder engine provided the only efficient answer to the requirement for increased air in the cylinders to burn the fuel necessary for a 2,000-kw rating of the engine. Initial pressure charging tests made a number of years previously had proved the feasibility of turbocharging this engine. These tests were made with standard direct-acting blowers used in series to raise the air pressure ratio to about 1.7 to 1. The data obtained indicated that:

- Pressure ratio should be 2 to 1 or higher
- Adequate air could be supplied to obtain 180 bhp per cylinder
- Blower horsepower would be excessive with mechanical drive
- An exhaust driven turbocharger would provide a specific fuel consumption of about 0.37 lb per bhp-hr
- Peak combustion pressures would be increased about 40 per cent, with nominal compression ratio reduced from 16 to 1 to 14.5 to 1.

With this background the developmental program went forward to apply turbochargers and manifolding to obtain the desired performance. Improved engine parts also would be needed to obtain long service life under the increased mechanical and thermal loads of the 2,000-kw rating. It was recognized that one of the major problem areas would be the response characteristics of a turbocharged, two-cycle engine.

*For Mr. Brownell's biography and photograph, please see page 58 of the April-May-June 1959 issue of the GENERAL MOTORS ENGINEERING JOURNAL. This is the second paper in this Volume contributed by Mr. Brownell, chief engineer of Electro-Motive Division.



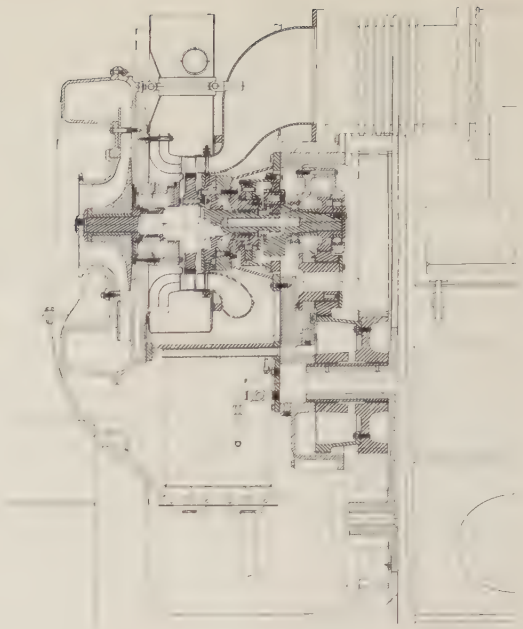


Fig. 1—Turbocharging the 16-cylinder Diesel engine was accomplished by using a centrifugal compressor and single-stage turbine mounted at the rear of the engine and driven by a planetary gear (left). A simple collector type manifold was used to avoid increasing the overall height of the engine. To minimize thermal stress problems, the manifold was made in four sections joined by flexible connectors. The planetary gear drive has an overrunning clutch. The clutch allows rotation of the outer gear when the exhaust gas energy is sufficiently high to drive the compressor shaft faster than the speed provided by the engine planetary gear. Hence, the turbocharger is free running at high loads to provide high engine mechanical efficiency and high air flow. For low loads, as well as starting and acceleration, the positive gear drive by the engine (right) enables the turbocharger to deliver the required air.

Fast response is necessary to obtain the close frequency regulation required in a generating set. This fast response is easily provided by a two-cycle engine with mechanically driven blowers. It has the advantage over a four-cycle engine of a power stroke of each piston for every crankshaft revolution. The blower provides an excess of air at light load that aids in fast load acceptance. As an example, the engine for the 1,000-kw plant demonstrated that it could accept a change from zero load to full load at 60 cycles with 0.4-cycle variation and full recovery in 1.5 seconds.

In a turbocharged, two-cycle engine the response is affected by rotor inertia of the free-running turbo-compressor, and by the low useful energy available to the turbine at light loads. In a two-cycle engine the mixing of scavenge air with the exhaust reduces the gas temperature and thus reduces the usable energy level of the gases entering the turbine. Therefore, air for starting, light load operation, and acceleration must be provided by means additional to normal turbocharger operation.

One solution for driving the turbine was the use of the pulse energy available from the exhaust "blowdown" occurring during initial exhaust valve opening. This method provided self-sustained operation of the turbocharger, but air for starting and acceleration still was not adequate.

A second solution was the use of a mechanically driven blower in series with a free-running turbocharger. An intercooler was placed between them to reduce the blower work and temperature problems. Prototype turbocharged engines were built with this arrangement, with a rating of 1,500 kw at 720 rpm alternator speed. Because a single turbocharger required too much space, two smaller turbochargers were mounted on top of the gear train housing at the rear of the engine.

Evaluation of this 1,500-kw turbocharged engine demonstrated the following:

Advantages

- Proper air-fuel ratio could be maintained and clean exhaust was assured
- Both intake and exhaust noise levels were lower due to the turbo-compressor, and could be made acceptable with less silencing treatment than the standard engine.

Disadvantages

- Better matching of the turbine and compressor to the requirements of the engine would be necessary to reduce the specific fuel consumption below 0.38 lb per bhp-hr
- The acceleration problem was not completely solved
- Installation space was excessive for many applications of turbocharged engines by Electro-Motive Division
- Total cost of this arrangement was too high.

To overcome the disadvantages, a gear driven turbocharger was designed for mounting at the rear of the engine. This turbocharger contained a centrifugal blower and single-stage axial turbine with a planetary gear drive (Fig. 1). This arrangement required no more space than the blowers it replaced. Aftercoolers were installed in the air ducts between the compressor discharge outlets and the engine air box sections. The turbocharger is gear-driven at light loads, starting, and acceleration, but is free running on exhaust energy at higher loads.

The specific air requirements of the engine were determined by tests to provide design information for the turbine and compressor. The test data were obtained by supplying air to the engine at variable flow rates and pressure, with a restricting valve on the exhaust outlet in place of a turbine. The engine variables studied included compression ratio, peak pressures, air flow rate, air box pressure ratio, exhaust temperatures, and specific

fuel consumption over a range of horsepower and rpm values.

Engine requirements for long service life under the higher mechanical and thermal loads were determined by calculation and tests. A compression ratio of 14.5 to 1 instead of the standard 16 to 1 was selected for the turbocharged 2,000-kw engine. Peak combustion pressure under this operation, and the selected speed of 900 rpm, were used for design calculations for the piston and rod assembly, bearing loads, and crankshaft stresses. A new exhaust cam profile was designed by the "polydyne" method to insure "no follow" speed above 1,000 rpm.

Tests also included strain gage analysis of the crankcase stresses, and of a new piston design and new injector rocker arm. Thermocouple tests were made on new piston and cylinder head designs. Engine testing of various piston and connecting rod bearings as well as the new piston, piston rings, cylinder head and valve designs was carried out for thousands of full load hours.

Applying Noise Control

The noise control approach employed in the design of the individual power generating units was to a great extent governed by results obtained from previous tests concerning the silencing of both the normally aspirated and turbocharged Diesel engines. Basically, the noise control problem is established by the turbocharged, two-cycle Diesel engine mounted rigidly to a metal base which also serves to support a rigidly mounted sheet metal enclosure. The three noise emitters which warrant the most consideration for noise control are the air intake, exhaust, and engine mechanical noise. Of these three, the noise created by the turbocharger compressor at the air intake is the most readily distinguishable and objectionable.

In establishing the predominant noise propagation paths that would be realized, the following information was considered:

(a) Airborne sound emitted from the Diesel engine components which is transmitted directly through the enclosure to the surrounding area

(b) Airborne sound emitted from the Diesel engine components which is reflected off the interior of the enclosure and acts to supplement the airborne sound in (a) above

(c) Structural vibration, created by the Diesel engine components, which can be conducted as structure-borne sound through the mounting base to the enclosure walls (Fig. 2).

Noise Reduction Near the Source Was a Solution

The initial step in providing noise control for the power generating unit was to consider what could be done to reduce the noise near its point of origin. It was felt that this action—other than quieting the noise source itself—would be the most direct and effective method as well as the most economical. Previous noise evaluation tests conducted on the turbocharged engine indicated that the two predominant noise emitters requiring silencing were the exhaust and air intake. On this basis, therefore, an air intake silencer and an exhaust muffler were designed as the first step for noise control.

Air Intake

The noise generated at the engine air intake had been established from previous noise analysis tests to be attributed to the turbocharger compressor which is a single stage, centrifugal type. At full engine speed of 900 rpm, the 16 compressor impeller blades revolved at 18,000 rpm. A calculation of the fundamental frequency showed it to be 4,800 cps for a full load turbine speed of 18,000 rpm.

The phenomena that occur within the compressor to create the noise under study have been theorized as follows. When the air flows from the atmosphere to the inlet of the compressor, it is interrupted by the necessary chopping action of the impeller blades. Pressure variations in the form of sound waves travel up the incoming air stream and enter the atmosphere producing noise easily audible to the ear and characterized by a high pitched whistle. The objective, then, was to design a silencer which, when placed between the atmosphere and the compressor inlet, would provide noise control by reducing the pressure variations before they reached the atmosphere.

Since it is well established that the tendency of higher frequency sound is to keep to a beam down the center of an air channel and not flow laterally, the use of an acoustical *target* or shield to trap this sound was indicated. This target could be considered as both a dissipative and non-dissipative type of silencer since

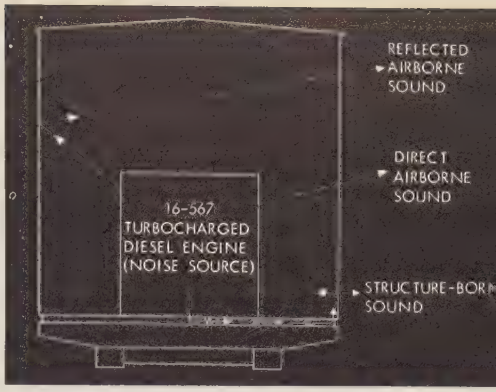


Fig. 2—In the noise control studies of the Diesel-electric generating units, the mounting arrangement and the housing of the units established the predominant paths of noise propagation. The engine-generator set is rigidly mounted to a fabricated steel base which in turn supports the enclosure consisting of 11-gage sheet metal panels reinforced by 2-1/2-in. by 2-1/2-in. by 3/16-in. channels. The overall dimensions of the enclosure are: 38 ft long; 10 ft, 6 in. wide; and 11 ft, 4 in. high.

absorption of sound energy and the reflection of sound energy back to the source would result. Parallel baffles or splitters are generally known to provide attenuation at the middle or high frequencies. These two basic principles were, therefore, incorporated into an air intake silencer.

The physical shape of the silencer was designed to allow for 17.5 sq ft of air filtration element. Sound absorbent material was used to line the top, bottom, and a portion of the wall around the inlet nozzle of the silencer box. The acoustical target baffle and two splitter baffles were arranged vertically within, in such a manner that no "line of sight" transmission of compressor noise was permitted (Fig. 3). With the silencer baffles located at what was felt to be the minimum distance from the inlet nozzle of the compressor, the air flow velocity was calculated to be less than 40 fps. The thickness and density of the insulation were selected on the basis of high sound absorption coefficients at a frequency of 4,000 cps.

Exhaust

To control adequately the noise created by the exhaust gas upon its exit from the turbine, it was reasoned that a muffler design would be necessary to convert the low frequency pulsating exhaust flow to a continuous gas stream. In this way, the exhaust gas entering the atmosphere would flow in a comparatively smooth and quiet stream. A muffler

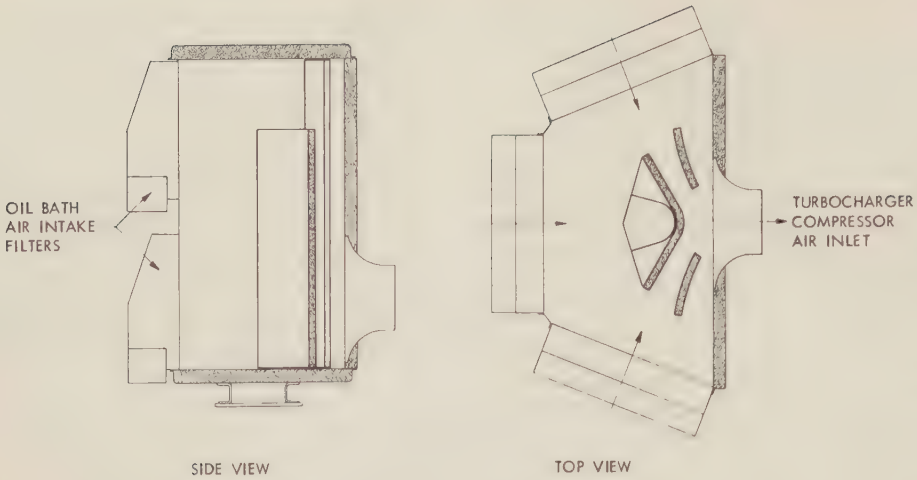


Fig. 3—The acoustical *target* and splitter baffles used in the compressor air intake silencer are shown in these cross sectional views. The baffles were designed to allow for re-positioning. This permitted adequate testing to determine the final location which would provide optimum silencing and no adverse effect on the volumetric efficiency of the compressor system. The sound absorbent material used in the lining of the silencer, on the acoustical target, and on the splitter baffles was a resilient type, glass fiber insulation. The material had a density of 1-1/2 lb per cu ft and was coated on one side with black pigmented vinyl to resist air erosion. Glass fibers having an average diameter of 3 microns were bonded with a thermosetting phenolic resin. The material thickness was 1-1/2 in. on the lining of the silencer box and 1 in. on the target and splitter baffles. A 16-gage, perforated metal grille with 35 per cent open area was installed as a protective facing for the sound absorbent material.

which provided this condition was furnished by an outside supplier. The muffler was a non-dissipative type denoting that no means for sound absorption are incorporated within its structure. The design was based upon the following data and requirements:

- Volumetric rate of flow = 20,000 cfm
- Exhaust gas temperature out of turbine = 800°F
- Exhaust gas velocity out of turbine = 275 fps
- Maximum pressure drop across muffler = 6 in. H_2O
- Cross-sectional area of muffler = 7.6 sq ft
- Length of muffler = 11 ft.

Confining the Airborne and Structure-borne Noise

After making provisions for noise control near the source of the predominant noise emitters, the next step was to treat the total engine enclosure acoustically in an attempt to confine the noise being propagated through the various paths mentioned previously.

Vibration Isolation

One approach was to consider using resilient mountings to prevent the structure-borne transmission of machine vibrations to a supporting member where the vibrations would be radiated as airborne sound. However, the existing design and manufacturing procedure of the 2,000-kw unit did not economically adapt themselves to the application of a resilient mounting material between the engine base and the enclosure. Another means of noise control, therefore, was introduced to eliminate the effect of this path of noise propagation upon the enclosure.

Vibration Damping

Reduction in the amplitude of vibration transmitted through an interconnected structure from the machine to its enclosure results in less sound being radiated into the air. This reduction can be accomplished by applying a damping material to the enclosure panels that are responsible for radiating the objectionable sound. The vibration damping material does this by converting part of the energy associated with the vibration into heat energy which otherwise would have produced airborne sound. Thus, in lieu of resilient mountings for vibration isolation, the design used a vibration damping material on the engine enclosure.

The type of material selected was partially based on information provided by the Geiger Method[2] which yields a number denoting vibration decay rate in decibels per second. This number indicates the damping capacity of a treatment and is determined by a laboratory test procedure developed by the late Paul H. Geiger. The higher the decay rate number, the greater the damping. Other considerations taken into account in the selection of a vibration damping or mastic deadener were the method of application, type of surface film, temperature sensitivity, flammability, drying conditions, water absorption, and resistance to lubricating and fuel oils. The mastic deadener chosen was based upon a low density inorganic mineral with synthetic resin binders which has a peak damping efficiency at a temperature of 70°F.

The deadener was supplied in a semi-fluid form and was spray coated to a thickness of ¼ in., which is twice that of the enclosure panel. This 2 to 1 thickness ratio was recommended by the manufacturer to achieve the most complete deadening. Complete coverage of the enclosure walls and portions of the roof was made.

Sound Absorption

To complete the noise control treatment of the engine enclosure, some means for confining the airborne sound was needed. Absorption material was, therefore, applied over the area on the interior of the enclosure where the mastic deadener material had been applied

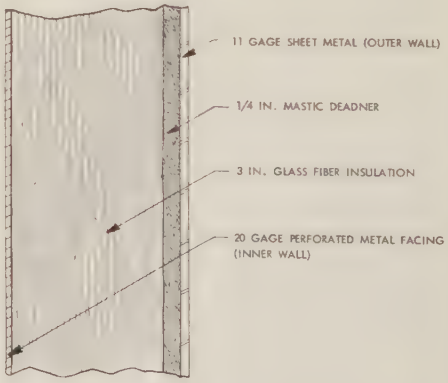


Fig. 4—The noise control measures taken for the enclosure walls are illustrated in this cross sectional diagram. The sound absorbing material was applied to the 1/4 in. mastic vibration damping material. This sound absorbent was a 3-in. thick, resilient-type, uncoated, glass fiber insulation with a density of 1/2 lb per cu ft. The fibers were bonded with a thermosetting phenolic resin. The protective facing was a 20-gage perforated metal grille with 22-1/2 per cent open area.

previously (Fig. 4). Since the airborne noise emanating from the engine and its components was composed of a variety of frequencies, the sound absorbent material was chosen on the basis of high sound absorption coefficients over a broad band of middle to high frequencies.

Noise Control in Aspirator

An aspirator is mounted on the roof of the enclosure at the outlet of the exhaust muffler. The primary purpose of this aspirator is to expell hot air that accumulates within the enclosure. For additional noise control, advantage was taken of this aspirator by lining it with sound absorbent material. Previous applications of this lined exhaust aspirator showed substantial reductions in high frequency attenuation in the broad band noise created by the exhaust as it enters the atmosphere.

Two types of sound absorbent material were used to line the interior of the duct. An *outer layer* facing the gas stream consisted of a 1-in. thickness of resilient-type, unbonded borosilicate glass fibers of 4 lb per cu ft density which could be used at hot face temperatures of 350°F to 1,000°F. This insulation was combined with an *inner layer* of resilient-type, unfaced glass fiber insulation of ¾ lb per cu ft density and 1-in. thickness. A 16-gage perforated metal grille having an open area of 40 per cent protected the insulation.

Integrating the Electrical System for Control and Protection

As described in the previous JOURNAL paper, the broad design objectives of the peaking plant included unattended operation, reliability, economy, fast starting (when required), and fail-safe protection of the plant. To accomplish these objectives, several problems had to be solved in integrating the electrical system. It is of interest to examine some of these problems, their relationship to the objectives, and their solutions.

In the design approach, there were five major sub-systems to be integrated:

(a) Engine speed control

(b) Generator excitation

(c) Power distribution

(d) Accessory control

(e) Protective system.

Engine Speed Control

Engine speed control was largely a matter of governor control and engine starting. The unattended operation and fast start requirements indicated an electrically controlled governor in which a major speed change from idle to full speed could be made swiftly, with vernier control for speed adjustment during synchronizing and loading. This problem was met by an electro-hydraulic governor having an idle solenoid (also used as a shutdown device when de-energized), a full speed solenoid, and a governor motor. To be able to have solenoid control and motor control on a single governor required disengaging a motor clutch when the solenoids were being used. The use of this governor fixed the operational characteristics and part of the logical design necessary to integrate it into the system (Fig. 5).

Generator Excitation

Generator output control, to be achieved without an operator, obviously required a new approach to the old problem of voltage and current regulation. What to do when line voltage swings presents some problems not readily handled by conventional regulating equipment. For this peaking plant system, the solution was a regulator with the unique features of voltage matching before breaker closure and current limit after breaker closure (Fig. 6).

Faster response and greater reliability were engineered into the excitation system by a magnetic amplifier exciter to replace the conventional rotating exciter. This static exciter was in reality a power stage of the regulator, and allowed direct regulation of generator field by the regulator. Elimination of the exciter brush and bearing maintenance was a major step toward higher reliability.

In central stations, the operator can adjust generator fields to control output voltages for voltage matching during synchronizing and for control of reactive current flow. On unattended stations, these features must be designed into the equipment.

The problem of matching generator voltage to line voltage during the synchronizing period was solved by a voltage matching circuit added to the regulator. This circuit essentially switched out the reference voltage normally established by the voltage adjusting rheostat, and substituted the line voltage as a reference.

Generator overcurrent protection was complicated by the requirement for unattended, self-protected operation.

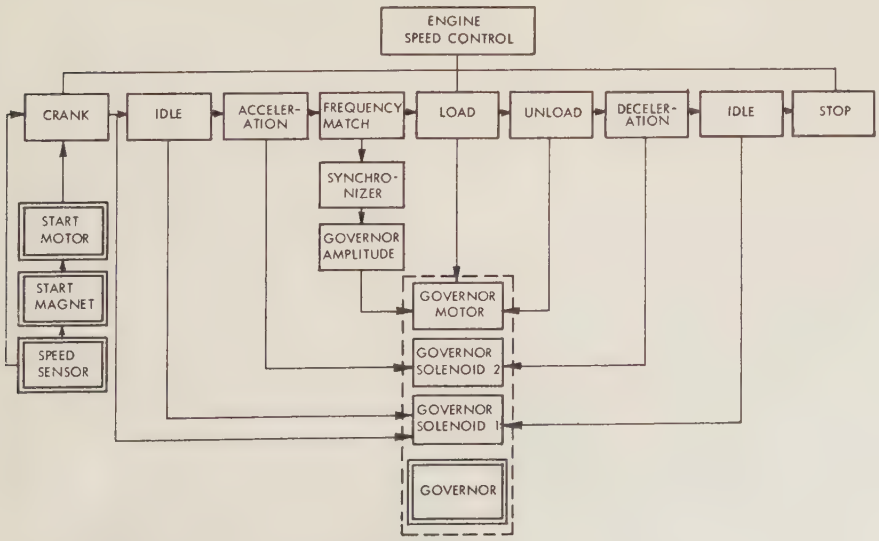


Fig. 5—Engine speed control was achieved by integral operation of four major elements: governor, speed sensor, start magnet, and start motor. Cranking of the engine, while relatively isolated to one phase of operation, was complicated by the low cost and fast start requirements. To economize, a single battery was used, the capacity of which was enough to crank only one engine at a time. This required a selection circuit to ensure that no more than one cranking motor was connected at any time. Further, since a cranking motor pinion must be disengaged to protect the motor from overspeed, starting magnet control was arranged to be responsive to a speed sensing device. The design utilized a tachometer generator output to sensitive relay inputs which detects zero, idle, and full speeds.

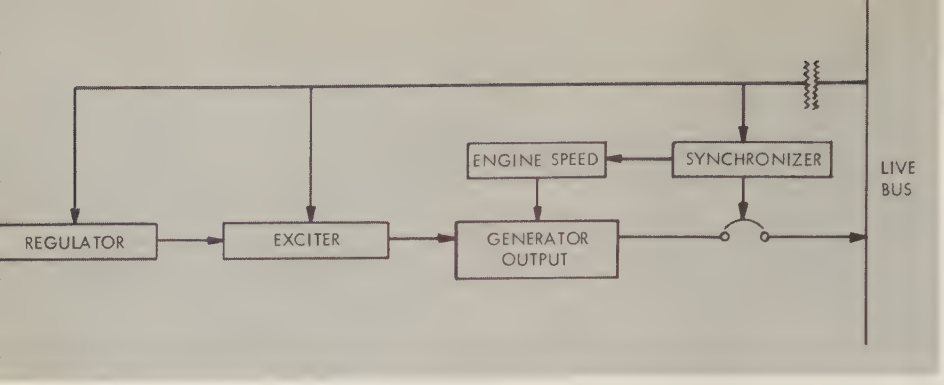


Fig. 6—Unattended operation is provided by some special features: static (magnetic amplifier) regulator, exciter, and synchronizer for reliability and performance; voltage matching and current limit for paralleling and remaining on the line through wide voltage fluctuations; and precise and repeatable accuracy of automatic circuit breaker closure.

Normal cross current compensating and overcurrent protective relay techniques are inadequate. When line voltage dips with standard regulation, either the generator is disconnected from the line when it is needed most, or the generator is subjected to overcurrent. With the current limit method, it was possible to overcome both problems since, as line voltage dropped, a point was reached where current did not increase with further drop. The generator did not trip off and was fully protected (Fig. 7).

Automatic synchronization—a *must* for this peaking and reserve application—had to provide reliability and fast, accurate operation.

A magnetic amplifier design for reliability incorporated proportional control for driving the output of the governor amplifier to the governor motor. The result was the driving of engine speed directly to synchronism without the pulsing techniques commonly used in speed matching.

An anticipation circuit permitted immediate and precise breaker closure when the engine speed was within a given band and phase voltages were matched.

Power Distribution

Power distribution studies on a low-cost, integrated control center suggested a unified cabinet approach. A five-section cabinet with a single set of metering equipment which normally reads total plant output, but which can monitor each unit output, provided the information necessary for an unattended station. The separate switchgear center provided both lower cost, and space and weight savings (Fig. 8). Ease of installation dictated that power interconnections be flexible and low cost. Buried cabling from the three generating units to the central control unit met this need adequately. One set of output terminals from the central bus in the control unit provided for either overhead or underground tie-in to the utility system.

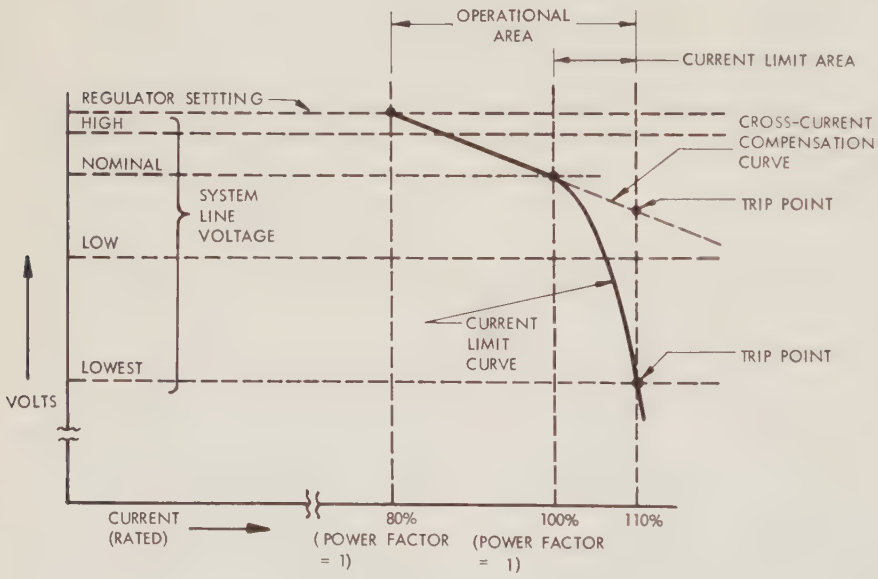


Fig. 7—Conventional cross current compensation follows a straight line function of increasing current as line voltage drops, resulting in a trip to protect the generator. Cross current compensation with current limit follows a conventional straight line until near generator rating when the limiting curve is reached. The droop then becomes so rapid as to prevent generator overcurrent, and the trip point may be moved so as to trip only when "lowest" voltage (external fault) occurs. Another feature of current limit is the ability to operate at full rated reactive current for power factor correction regardless of line voltage fluctuations. This is accomplished easily by setting the regulator rheostat at a point high enough to always be operating in the limiting area. Current-limit type of operation is practical because of the application of this peaking and reserve plant to a utility power system which provides a constant, known kilowatt load on the generator.

Accessory Control

Accessory control for unattended operation provided several interesting problem areas. A fast start required engine oil to be at a temperature of about 100°F to avoid undue engine wear. Heating was done by immersion heaters in the engine water, and circulating pumps in lubricating oil and water systems. The design called for the heaters to cycle on and off automatically to maintain a given water temperature. The pumps run continuously to circulate the engine water and lubricating oil since the peaking application is such that they must be rated for continuous operation at any rate.

This method keeps the engine oil above 100°F for fast starting, with no deterioration of oil by hot-spot temperatures (as would occur if heaters were directly in the oil).

Battery charging was an important consideration for an unattended station especially in view of the functions of engine cranking and three-unit control from one battery. The charger provided was of the saturable reactor type with a control scheme which provided periodic checking and charging controlled by a temperature-voltage compensation relay. This resulted in batteries being cycled and maintained automatically except for water addition. The charger was of sufficient capacity to provide control power during periods of low battery voltage, such as during cranking.

Protective System

Protective systems for both the high voltage system and the control sequences were necessary.

High voltage system protection was simplified by recognition of some facts of application. Unit overcurrents might

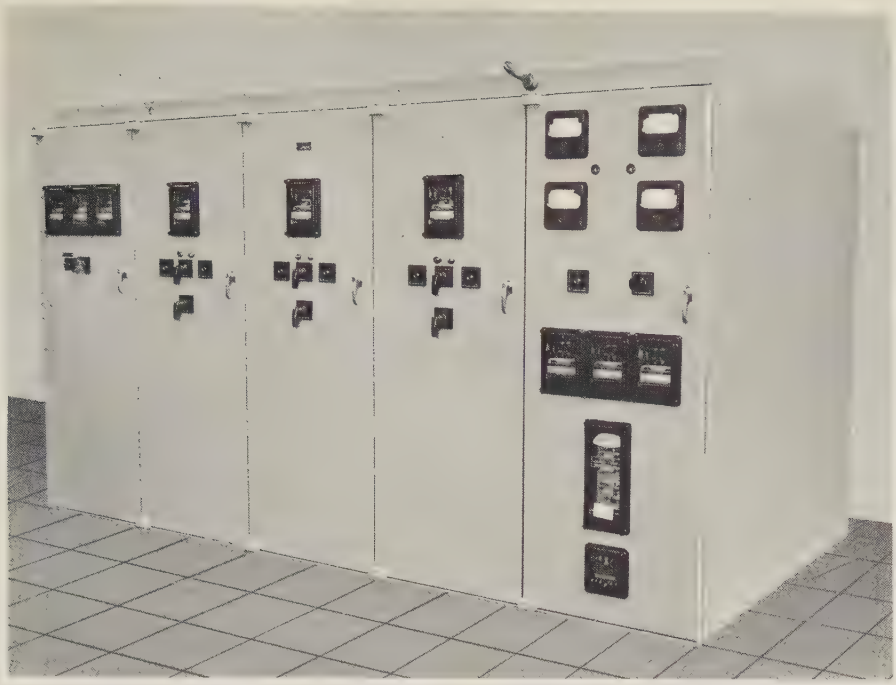


Fig. 8—The five-section cabinet is arranged by function. The right hand unit contains output bus potential and current transformers, metering, and bus protective relays since the unitized bus passes through this cabinet to customer terminals. The three central sections each house a drawout air circuit breaker. The left hand cabinet contains a control power transformer, potential transformer for the unit immediately to its right, and space for a transformer for a fourth circuit breaker, whose cabinet would be placed to the left, if required. The potential transformers for the other two units are in the right hand cabinet.

system (Fig. 6), and the economic necessity of using a single battery and synchronizer for all three Diesel-generator units.

A sequential control scheme was decided upon, based on each stage of operation being initiated by successful completion of the preceding stage. This allowed the total time required to be dependent only upon the actual time required by each stage of operation rather than waiting for time-out if the operation was completed.

In the use of common equipment (battery and synchronizer), a random selection type of circuit design was necessary because of varying equipment characteristics. For example, before cranking each unit, a pinion on the starting motor must be engaged with a gear on the engine. The physical alignment of these gear teeth is such that they do not always mate on the first try. To save time, all three starting magnets for engaging the pinion and gear are energized simultaneously. The selection circuit was then designed to select the first pinion engagement, and crank that engine first.

occur from external faults, internal faults, or regulation difficulties. External faults could be detected by voltage-restrained overcurrent relays on the output bus. Internal faults would operate a differential relay comparing the sum of unit generator outputs with the total plant output. Regulation difficulties could be detected by overcurrent or undercurrent relays in the field circuits. This permitted good protection with only a single set of overcurrent relays on the output (Fig. 9).

Control sequence system maloperation and annunciation were minimized for best reliability, yet still providing full protection. Sequential stages were timed, and overall timing protected interstage malfunction (Fig. 10).

Analyzing a Typical Problem in the Electrical System

A typical system integration problem was involved in the fast start requirement for emergency situations. The objective of a minimum of 90 seconds to load the 6,000-kw output into a live bus from a standstill condition was established.

This problem was resolved in the combination of the *engine speed control system* (Fig. 5), the *generator output control*

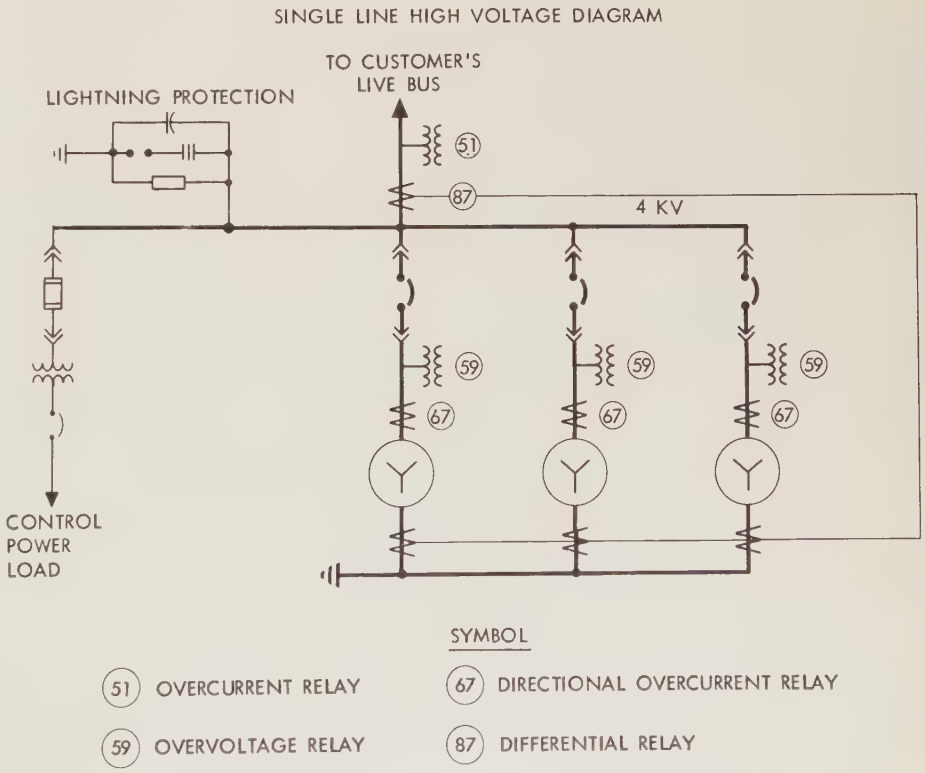


Fig. 9—External fault protection is provided by overcurrent relays with voltage restraint on the output bus. Internal ground is protected by differential relay detection of unbalance between current transformers on output and summing of individual generator output currents. Reverse power relays prevent motoring of the engines by a live bus.

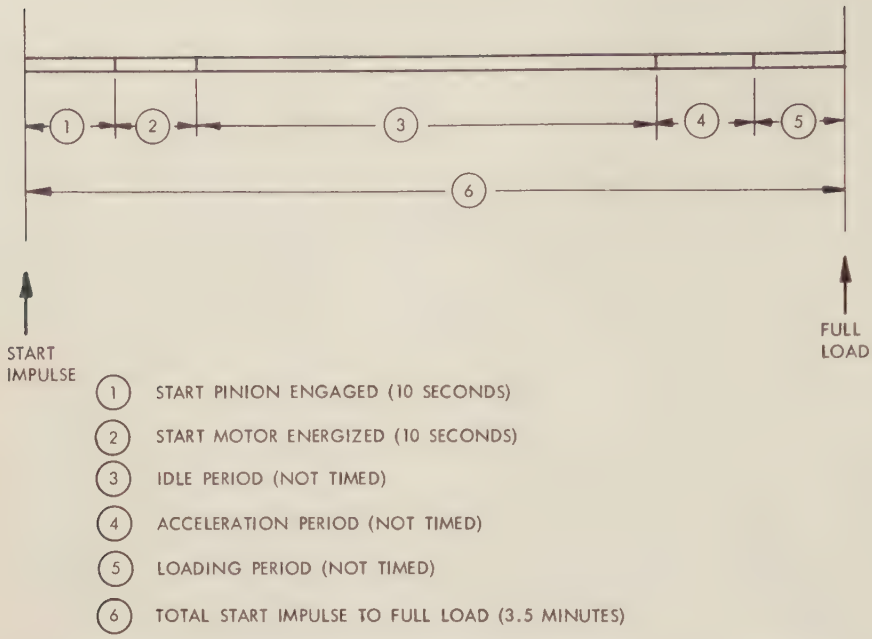


Fig. 10—The basic elements of the *start* system and their relation to the control system protection can be represented by this diagram. Periods *1* and *2* are critical, and equipment could be damaged if malfunction continued. Periods *3*, *4*, and *5* are subject to sequential failures which, although not dangerous to equipment, would be detected by the overall timing period *6*.

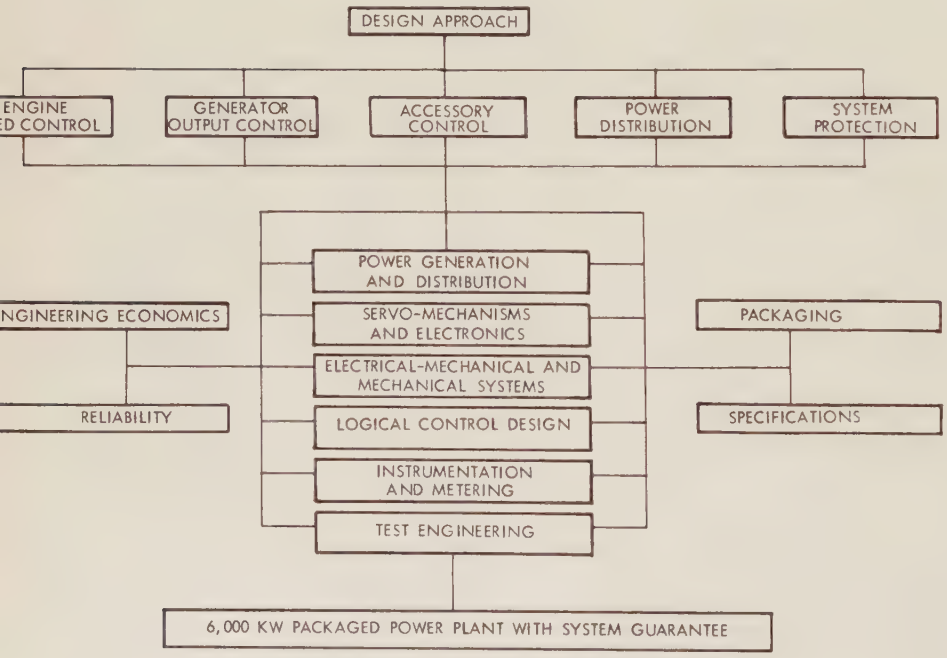


Fig. 11—A block diagram arrangement suggests how the knowledge and techniques in various branches of engineering had to be applied to integrate the major elements of the electrical system for the peaking and reserve plant.

Similarly, in the use of the synchronizer, each engine does not fire in the same cranking time. Therefore, a selection circuit was designed to detect which unit was ready first and permit immediate synchronizer utilization as against the other choice of connecting units always in the same sequence.

The end result was a system which, under most favorable starting conditions, was fully loaded in 35 seconds, and, under least favorable conditions, was always well within the 90-second objective.

Summary

In solving the various electrical system problems, the designers had to apply the knowledge and techniques used in several branches of engineering. The principal ones might be identified as: power generation and distribution, servomechanisms and electronics, mechanical and electro-mechanical systems, logical control design, instrumentation and metering, and test engineering. Other areas which were important to the development also could be named such as engineering economics, reliability, packaging, and specifications (Fig. 11). And these areas similarly influenced the overall design approach to this new application of the Diesel-powered generating plant to peaking and reserve service.

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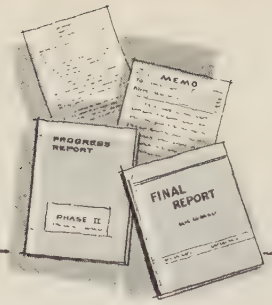
Technical Literature—An Aid to the Engineer



By EUGENE B. JACKSON
General Motors Research Laboratories

Technical literature is a necessary and valuable tool to the engineer. Intelligent use of technical literature prevents duplication of work, provides stimuli for new channels of thought, saves technical manpower, and enables the researcher to perform complete and effective work. The ability to use technical literature can be developed by any engineer who will learn to recognize the sources of reference material and the methods by which the references can be located.

Reference material available in many forms

A SLIDE rule is the accepted tried and true aid of the engineer—it saves him time, thus helping him get on with the important job. The printed word can likewise be a help to the engineer—it makes known the experiences of the past, prevents needless repetition of work done elsewhere, and provides sparks of inspiration for future work.

A few handbooks and textbooks no longer can serve as the engineer's total printed sources for his professional career. New engineering materials, new methods, and new extreme physical requirements of materials have conspired to complicate an already far from simple picture. A significant increase in expenditures for research and development at all levels likewise means that the contributions of an increasingly larger proportion of engineers are needed now than in the prewar era. An index of the growth of research is suggested by the increase in the number of technical journals in recent years (Fig. 1).

A recent evaluation of technical literature as a tool of the research person reads ". . . there are two kinds of research tools, first a tangible one measured by the huge investment in laboratory buildings, equipment, supplies, and service presently considered necessary to support the experimental activities of a research man, and second, an intangible one, consisting of technical information, both internal and external to the company, selected and considered in the light of the company's research objectives, so as to provide support for the mental and creative activities of the research man. All of the available skills and tools need to be brought to bear on the problem at hand in the most effective manner possible. Both are necessary.[1]"

Questions that come to mind include: "What is technical literature?", "Where can I obtain it?", and "How can I use it most effectively?"

What is Technical Literature?

Technical literature can be defined as being the record of past endeavors in technology. It may take various forms, such as books, periodicals, abstract services, looseleaf services, trade catalogs, preprints, reprints, documents from local, state, national or foreign governments, proprietary internal reports, military or Atomic Energy Commission security classified research reports, contract research reports, research correspondence, slides, films, photographs, and drawings.

Technical information may be obtained in as direct a manner as filling out the request card at the back of a periodical, by visiting a public, college, or industrial special library, or by means as elaborate as requesting a patent search or a critical bibliographic survey by a consultant for a substantial fee.

Persons who make it their business to acquire, organize, announce, and assist in the use of technical information are known variously as technical information officers, documentalists, or librarians. While they devote their full time to technical information and are eager to assist others to use it, such factors as the increasing volume of technical information, the increasing number of engineers, and the variation in availability of sources of technical information combine to make it advisable for the engineer to learn his own way around this field.

The engineer's colleagues in chemistry have had literature courses as part of their normal training for a number of years. In fact, the excellent books by Crane[2] and Mellon[3] outline the methodology that an engineer could utilize with profit for self-instruction. In engineering education, an introduction to technical literature methodology is frequently obtained by a unit in the engineering English courses or an orientation course. Here, some opportunity is given to learn the fundamentals of using the literature and the library. Typical problems are assigned that employ aids and techniques covered in this unit on a specific technical topic.

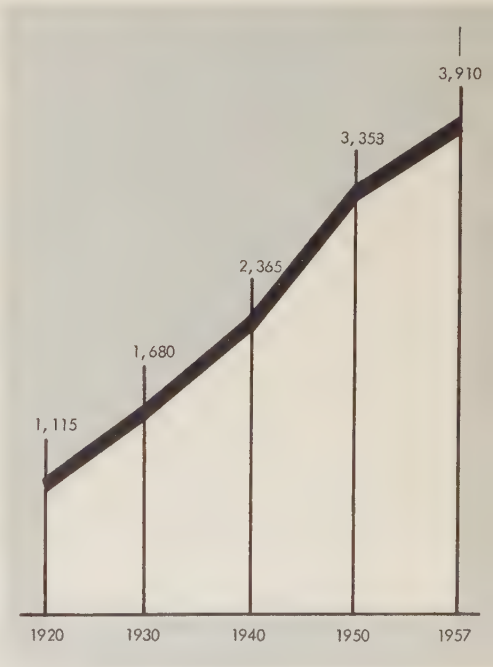


Fig. 1—The growth of scientific and technical journals in the United States since 1920 indicates the greatly increased amount of research being conducted today. The increased number of journals also reveals the vastly increased amount of published material of which the engineer should be aware in his work.

A New Book Distills Previous Knowledge

As a start in self-training the reader could embark upon a "tree of references" by looking at the ends of chapters or at the back of a technical book he has on his desk. These references could be located in a library, and they, in turn, normally have references themselves. The "tree of references" will fan out opposite to the way a family tree does in genealogy. From this, it may be seen that a reference in the readers' hand is a distillation of previous knowledge whose ancestry may include many types of technical information of varying age and source (Fig. 2).

One interesting method of examining the relationship of a book to its reference sources is to investigate and classify its references. From this examination, conclusions can be drawn about the field of the book and possible reference sources in that field.

As one example, take the book by Simon Ramo and A. E. Puckett entitled, *Guided Missile Engineering*[4]. This book on a modern subject includes 151 references of which the earliest is dated 1914 and the latest 1957. Fifty-one per cent of the references are in the 1950's, 36 per cent are in the 1940's, and 12 per cent are before 1939. As to the kinds of material referenced, 42 per cent are references to books, 46 per cent to periodical articles, 7 per cent to research and development reports, 2 per cent to technical society preprints, and 2 per cent to symposia. It can be concluded that books and periodicals form nearly equal sources of information for this book on a modern subject, that over half of the material is less than five years old, but that it is necessary to go back 35 years to get all relevant references. The percentages of recency of material tabulated for this book agrees remarkably with a study of the ancestry of 800 references in recent articles in leading electrical engineering periodicals[5].

A book devoted to references for a special topic also can provide some interesting information regarding that topic. As an example in engineering, take the book by R. R. Hawkins entitled, *Scientific, Medical, and Technical Books Published in the United States*[6]. For the 2,052 books listed on engineering, a tabulation of the books by engineering fields shows the following: mechanical engineering, 24 per cent; electrical engineering, 18 per cent; civil engineering, 17 per cent; general engineering, 13 per cent; mining and metallurgical engineering, 11 per cent; and chemical engineering, 9 per cent. (The last mentioned figure is deceiving because a very large number of materials of theoretical chemistry were listed elsewhere in the volume.) An inference could be made that a greater number of important books existed in the mechanical engineering field than, for example, in mining and metallurgical engineering.

Guides to Using Literature Available

The "do it yourself" approach to engineering literature searching has been likened to detective work, in that both efforts are to establish facts based on an accepted procedure and interpretation of evidence encountered.

For a modest investment, several books can be obtained which can aid the self-development of using technical literature. One of these, *Guide to the Literature of Mathematics and Physics Including Related Works on Engineering Science*, by N. G. Parke III, covers the principles of reading and study, self-directed education, and literature search. A briefer study listing reference works, textbooks, and journals is a compilation of Irma Johnson entitled, *Selected Books and Journals in Science and Engineering*. The more ambitious could consult Robert Murphy's *How and Where to Look it Up: A Guide to Standard Sources of Information*, which is intended specifically for the non-professional literature searcher. Although its cost is higher than the first two books, it covers a wide scope of subject fields in addition to engineering.

Developing a List of Reference Sources

A summary of the various guides to using technical literature is beyond the scope of this paper. In fact, a recent paper on mechanical engineering documentation took 14 pages for that one topic, and it was intended for experienced literature users[7].

Perhaps the best method to offer some instruction is to characterize the types of literature, and to use one illustrative subject and go through the kinds of material available (see the Appendix). Using this approach as a guide, any reader could develop a similar list on a subject of his choice.

Several types of literature are encountered when developing a list of references. These include books, periodicals, government documents, proprietary internal reports, and research correspondence.

Books

Books summarize information which is available elsewhere in piecemeal form, but tend to be less recent than periodical articles. New books may be located through the *Cumulative Book Index* in libraries, which is arranged by both subject and author. Card catalogs, book reviews, and technical periodicals are other valuable sources.

Periodicals

Periodicals exist in a wide range of forms and levels of presentation from the house organ featuring manufacturers products through scientific journals of the highest level. Sources like the Johnson List are helpful to indicate the leading periodicals. They are indexed in various sources, such as the *Aero/Space Engineering Index* of the Institute of the Aeronautical Sciences and the *Engineering Index*, available in card service and in bound annual volumes. Both of these services also include reprints from various societies, including both papers that will and will not be published in periodical form.

Government Documents

Government documents are issued in large numbers and are widely available for consultation in depository libraries (one in each congressional district). The index to these often valuable materials is the *Monthly Catalog* of the U.S. Government Printing Office. Other government documents are postwar government research and development reports. These are listed in a variety of sources, such as the Armed Services Technical Agency's *Technical Abstract Bulletin*, the Office of Technical Service's *U.S. Government Research Reports*, and the National Aeronautics and Space Administration's *Publications Announcements*.

Proprietary Internal Reports and Research Correspondence

Proprietary internal reports normally are not announced outside the organization doing the work or for whom the work is done. Research correspondence is indexed in some organizations, and affords a source of up-to-the-minute information that will be subject to modification.

One Form Can Give Various Kinds of Information

The physical form in which literature is encountered is significant because it normally determines the indexing medium where the literature may be located.

A second important characteristic is the kind of information that the piece of literature presents. This might vary from a directory of instrument manufacturers to a handbook on the use of radioactive materials to a history of glass making. Since titles may be misleading, an actual examination may be necessary to determine the kind of information included.

A list of kinds of information would include bibliographies, indices, abstract lists, dictionaries, directories, handbooks, encyclopedias, tables, standards, monographs, and textbooks.

Bibliographies

Bibliographies are lists of other materials and may be annotated, listed in the annual *Bibliographic Index* in libraries, or listed as references in other types of reference aids.

Abstracts and Indices

Abstracts may be descriptive or critical. The first merely explains what is included in the reference, while the second is an evaluation of the work reported there.

Dictionaries

Dictionaries may convert terms from one language to another, or be concerned with the nomenclature of one or a variety of related technical subjects. Entries are more concise than those in handbooks or encyclopedias.

Directories

Directories, which normally have very brief entries, may list members of a professional society, manufacturers, or accredited universities. Telephone books are valuable sources of up-to-date information, especially those of metropolitan areas that are available for consultation.

Handbooks and Encyclopedias

Handbooks usually summarize data concerning the topic from scattered sources. Individual chapters of handbooks often are written by specialists. Various tables are included which provide information on physical constants and other properties. Encyclopedias are broader in scope and normally contain references to other sources of information.

Standards

Standards are accepted specifications for purity, ruggedness, and practice. They may be issued by a trade group such as the Electron Tube Manufacturers Association, by a technical society such as the Society of Automotive Engineers, or by a national or international coordinating organization.

Monographs

Monographs are detailed treatments of a subject. They usually are lengthy, and are frequently on a less usual phase of a topic.

Textbooks

Textbooks normally are intended for instructional purposes, and the preface usually indicates the level of students for which they are written. They also may be valuable introductions to a subject for persons entering an unfamiliar field.

Summary

The literature search includes information in many forms and kinds and is never really complete. A guide line would be to make each search just a little more extensive than the circumstances—that is, the importance of the problem and the time limit—seem to indicate.

The information of the past added to the data of the present leads to the progress of the future. No one part of this equation is more important than the others. Systematic use of technical literature can assure that the first term of the equation will be as valid as the second term and lead directly to the result sought.

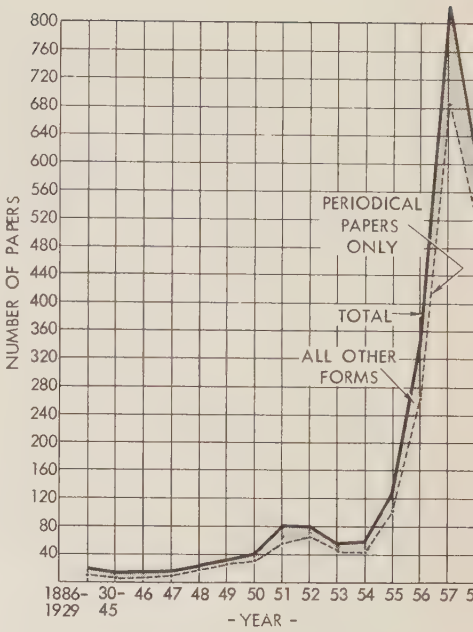


Fig. 2—By charting the growth of literature on space science, one can see its rapid growth in recent years. A sudden, large increase in the literature is seen in 1957, which probably was caused by the demand for space information following man's initial space probes. The chart also shows references as far back as 1886. Some of these basic studies are still significant, and should not be disregarded by those who consider space science a new field.

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A List of Technical Literature on Aeronautical Engineering

This appendix includes a selection of the most valuable technical literature in one field—aeronautical engineering. Using the guide and indexing media mentioned in the paper, a similar list could be developed on virtually any technical subject. The forms of literature referred to in the listings under *Bibliographies* and *Abstracts and Indices* are designated by the following key: books, *B;* periodicals, *P;* government publications, *GD;* government research and development reports, *RD*.

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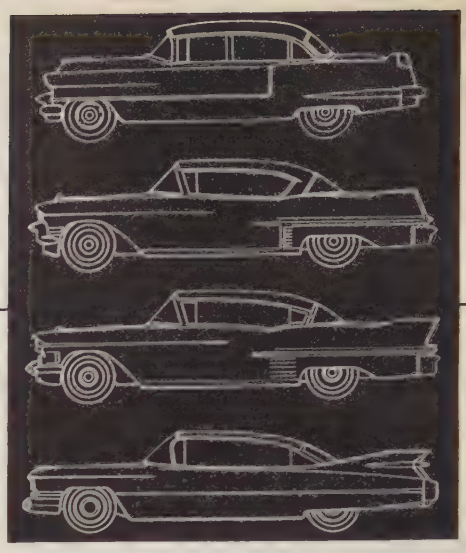
Development of the Annual New Car Model—From Styling to Assembly



The annual new car model development—from the first styling sketches to the time the first model rolls off the assembly line—represents a complex process which, through experience and know-how, has evolved into an orderly sequence of events. Developing a new car model requires time—time, for example, to establish the final styling and mechanical characteristics, time to complete engineering development tests on new and improved components, and time to prepare for production. How much time is required? Generally, a new car model requires approximately three years of developmental work before full production begins. However, some of the mechanical components, materials, safety features, passenger comfort concepts, and manufacturing techniques applied to the new model may have been under development for many years. Automotive engineers and stylists, therefore, continually work in the future. Today, as 1959 models roll off the assembly line, production engineers are completing plans for the 1960 model change-over, design engineers are completing the remaining engineering development work needed on the 1961 models, and stylists are finalizing on sketches and renderings which will establish the outward appearance for the 1962 model.

TIME is a very deceptive item to the automotive engineer and his design counterpart, the automotive stylist. During the course of a working day the automotive engineer can span one, two, three, or more years in his creative thinking and activity. And the stylist nearly always works in the future.

With the annual introduction of a new car model it is very natural for the engineer and stylist to consider that particular model "old hat," since they have lived with it through concept, development, and test. At the time the new model is introduced, their thinking is one, two, or three years ahead.

Take, for example, the 1959 Cadillac. Back in September and October of 1956 Cadillac engineers were building and testing the prototype of the 1959 engine (Fig. 1-left), an engine that was to have a 390-cu in. displacement, greater efficiency, and improved performance. At the same time, in the GM Styling Staff's Cadillac design studios, located at the GM Technical Center, stylists were finishing sketches and renderings that incorporated the outward appearance of the 1959 Cadillac (Fig. 1-right). These, of course, were early manifestations of thinking that dated even further back on the calendar.

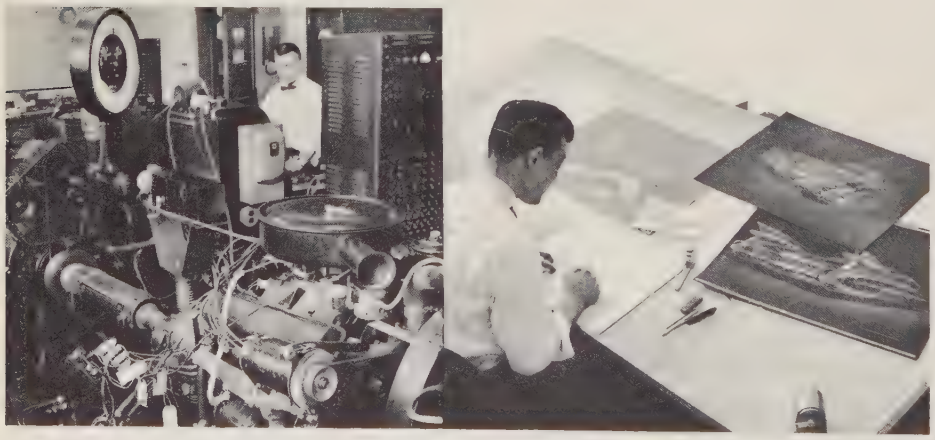


Fig. 1—Approximately three years before the 1959 Cadillac was introduced, two phases of the work connected with its development were nearing completion. One phase was concerned with developmental tests on the prototype 1959 Cadillac engine (left). The other phase consisted of the finalizing of sketches by stylists (right) which would incorporate the outward appearance of the 1959 Cadillac.

During this same September-October 1956 period, Cadillac engineers also were concerned with the start of production for the 1957 models and the remaining engineering development necessary for the 1958 models.

Schedule Establishes Lead Time Requirements

To remain aware of the many projects which run concurrently during the design and development of the annual new car model, an engineering schedule is prepared (Fig. 2). This schedule serves as an ever-present reminder of the current, immediate future, and more distant future projects which must be given consideration during the continuing development of a forward moving engineering operation.

A most significant function of this schedule is the reminder of lead time requirements for the successful culmination of an engineering program. These lead time requirements remain basically the same year in and year out, even though the engineering and styling move ever forward.

New Car Model Must Meet Many Requirements

Design trends represent a step-by-step evolution rather than merely annual mechanical changes. The final realization of a new car model is the result of a process of assimilation and modification.

In addition to improving on mechanical components and styling, the annual new car model design must attain, for example, the lowest tooling costs possible; must both anticipate and solve future engineering problems; and must give engineering consideration to problems of shipping, handling, and packaging to

By CLARENCE E. MORPHEW
Cadillac Motor
Car Division

The calendar becomes a stern taskmaster

obtain maximum utilization of storage space for the many components.

For each new car model the stylist, design engineer, and manufacturing engineer cooperate to establish a design which is the best obtainable in its line at a reasonable price. In addition, both the stylist and design engineer must attempt to be more discriminating than the customer.

The sequence of events which take place during the development of the annual new car model, from initial concept to final assembly, is basically the same for all GM car Divisions. The development of the 1959 Cadillac will be used to give a summary of the representative steps and procedures followed.

Early Development Stage One of Compromise

The general specifications for the annual new car model develop in the GM car Division. The objective of the specifications is to maintain and, if possible, improve the competitive position of the car Division's product in the market area in which it is engaged. To obtain this objective, the mechanical and styling features must have customer appeal and the car must be competitively priced.

There are two continuous activities which provide information helpful in establishing the general specifications. The design, development, and testing of improved mechanical components is a continuing activity on the part of the car Division's engineering department. Likewise, the development of new automotive styling concepts is a continuing activity on the part of the GM Styling Staff. These two activities, therefore, provide a choice of mechanical and styling features for management consideration when the annual new car model is contemplated.

When the car Division has agreed on tentative specifications these are then presented to top management. As soon as these tentative specifications are approved, final development is started.

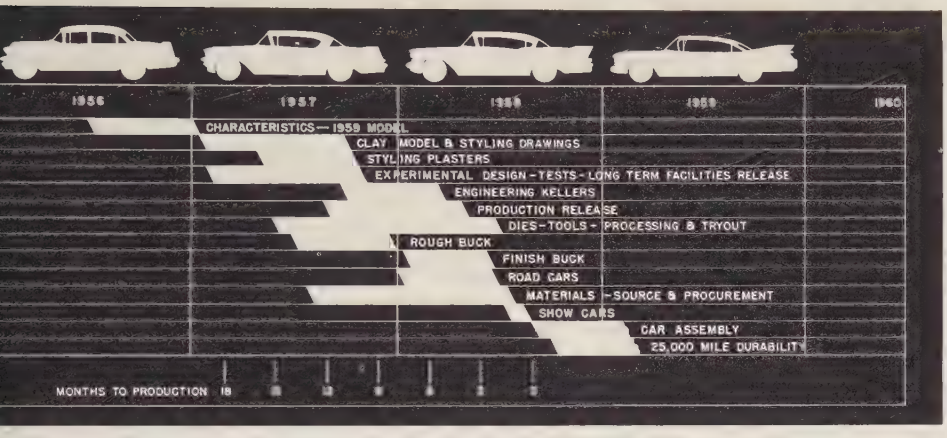


Fig. 2—Developing the annual new car model requires time, as evidenced by this chart which summarizes a breakdown of the styling and engineering work schedule for the 1959 Cadillac. Styling and major mechanical characteristics were finalized almost two years prior to introduction. The profile views of the 1956 through 1959 Cadillac indicate that at any one time engineers are working with four model year cars. While the 1959 Cadillac was in the early stages of development, the 1956 model was in production; arrangements were being completed for the 1957 model changeover; and final engineering development tests were being made on the 1958 model.

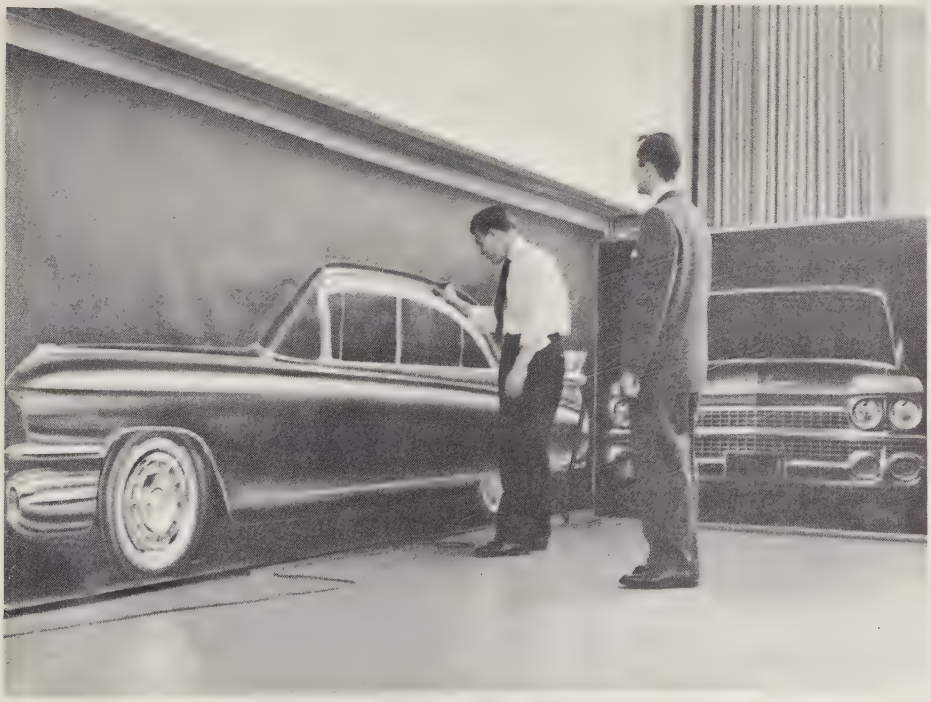


Fig. 3—From the many sketches drawn by stylists evolved the final styling concept for the 1959 Cadillac. Full size renderings were made to show exterior appearance (left). Also, full size line drawings showing exterior outline, seating arrangements, and interior details were made (above) to verify true proportions. Lines developed on drawings such as these were duplicated in wooden contour templates used to build a clay model (Fig. 4).

Fig. 4—As soon as full size drawings (Fig. 3) were made and approved, work was then started on a clay model of the 1959 Cadillac (left). When the model was completed and approved, plaster casts of the clay surface then were made. The casts were used to mold a glass fiber model (right), which was completely finished with paint, chrome, and glass to reflect all exterior and interior details of the finished car.

At this time, basic engineering specifications considered desirable by the car Division are then given to the Styling Staff.

During this early stage of development the specifications are subject to a great deal of change. The design and ultimate manufacture of an automobile requires extensive preparation and involves the work not only of men but *groups* of men. Consequently, there is much give and take, for example, between stylists and engineers and between various other groups such as production, purchasing, and sales.

As an example, mechanical requirements for both chassis and body exert a restraining influence on styling decisions. Also, improved styling features and mechanical components, which may be desirable in themselves, may involve increases in weight and cost. These improvements may have to be modified if performance standards and price position are to be maintained. Other influences such as manufacturing practicability, customer preference, and material avail-

Fig. 5—Seating bucks of the 1959 Cadillac were used to measure interior dimensions and provide a preliminary test of entrance and comfort conditions.

ability also are considered at this stage of development.

Stylists Give New Car Model its Shape

Once the basic styling theme is agreed upon, much work remains to be done to bring it to its final form. The first sketches, or renderings as the more elaborate colored drawings are called, are made literally by the dozens. The best features of each then are selected and combined into revised sketches. These selected designs are drawn full size to obtain true proportions. Full size drawings are made to show exterior styling, seating arrangements, and interior conditions (Fig. 3).

The current progress of the design is then exhibited and any unsolved problems discussed. Any modifications deemed necessary at this point are made and, after subsequent approval is obtained, the next step is taken.

This next step involves the building of a full-size clay model of the car, in which the general proportions are worked out in three dimensions (Fig. 4-left). All of the exterior shape, including front and rear bumpers, is worked out in detail on the clay model.

When the clay model is finished and refined to meet further modifications, provisional approval is given to proceed. Plaster casts of the clay surface are then made. These casts are used for drafting reference and preliminary die design and, eventually, to mold a glass fiber model. The glass fiber model (Fig. 4-right) is completely finished with paint, chrome, and glass to reflect all exterior and interior details of the finished car. During this period, seating bucks also are made (Fig. 5).

Approval of Exterior Appearance Paves Way for Body Tooling

As soon as final approval is given on interior appearance and body features, drawings and body specifications are released to Fisher Body Division. During this period, the body structure, body mechanisms, exterior trim appointments, and interior soft trim are developed for later tool design and assembly fixture requirements[1]. Fisher Body also tests various parts of the new body to see if any structural improvements can be made[2] (Fig. 6).

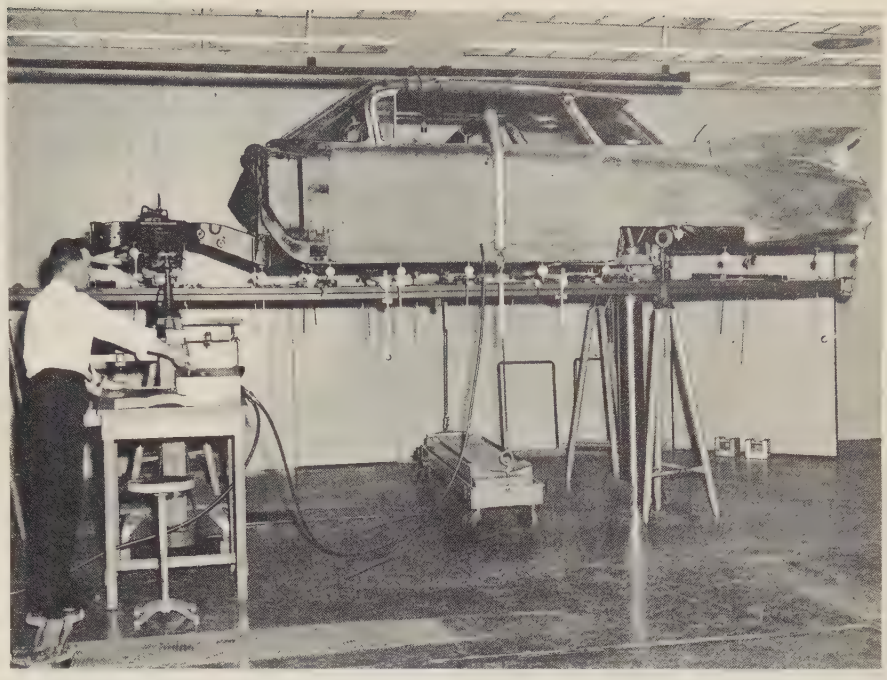


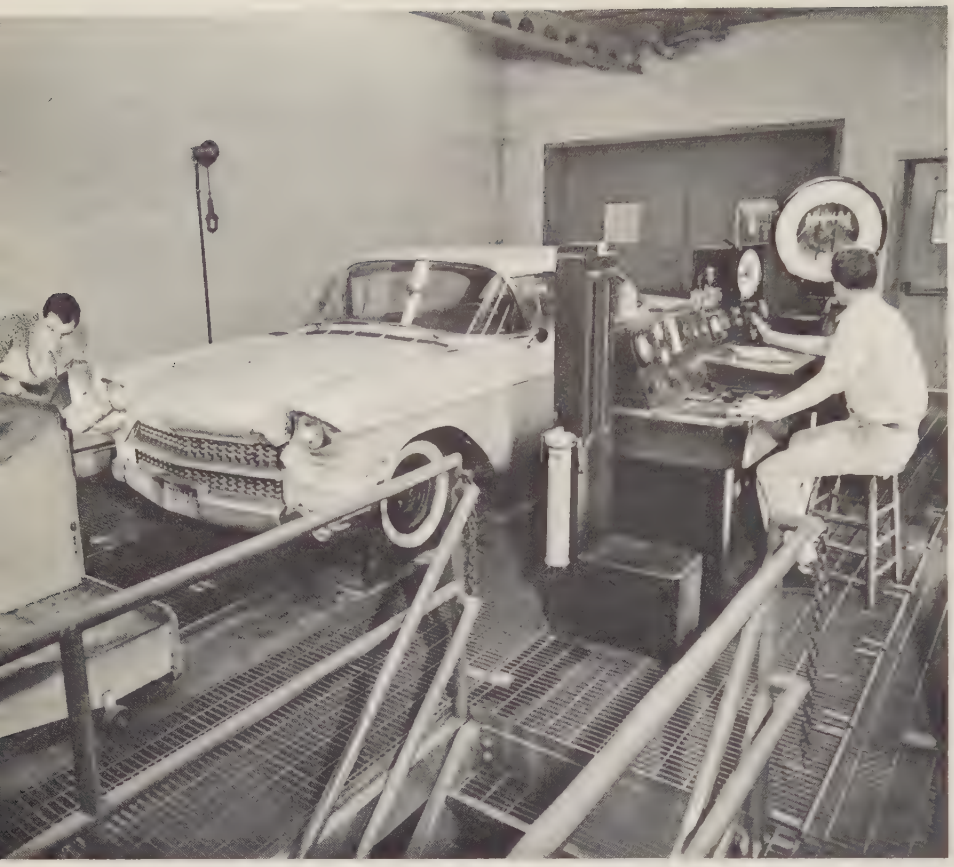
Fig. 6—A hand-built 1959 Cadillac body was made by Fisher Body Division and then subjected to structural tests. Here, a body-frame combination undergoes a test for beaming and torsional rigidity. Deflection resulting from torque loads applied to the frame was measured by indicators placed at specific locations along the frame side rails and rocker panels. The torsion test indicates the body's ability to resist twisting, as might occur when one front wheel hits a bump. Final road testing of the complete car serves to verify the laboratory results.

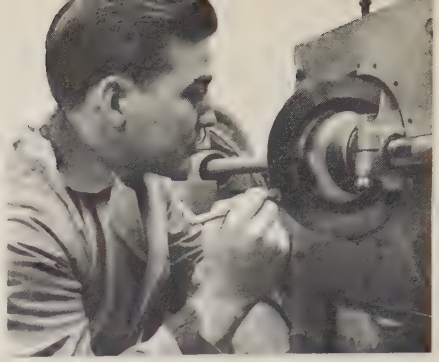
The front end appearance and car exterior sheet metal, other than that incorporated in the body, are developed by the Styling Staff and tooled by the car Division when the design is finally approved by top management.

During this period tool engineers begin their preliminary work and a short time later start the first Keller models. A Keller model is an actual size wooden model of a part, such as a fender or hood panel. The model is made to the exact contours of the finished part. The name Keller is derived from the Keller dupli-

Fig. 7—Cadillac staff engineers held meetings to finalize plans dealing with the engineering development of the 1959 model.

a





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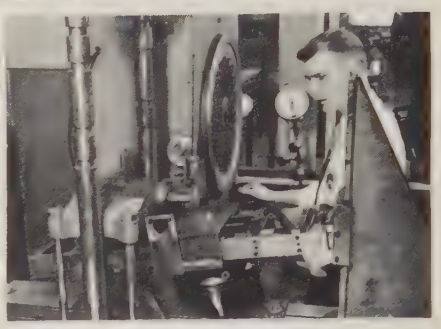

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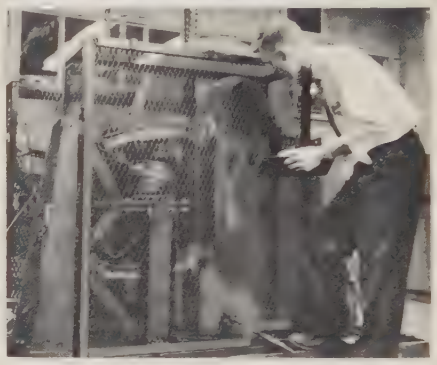

d

Fig. 8—Typical of the various developmental tests conducted on components for the 1959 Cadillac were: engine cooling tests (a); gear tooth contact checks on the differential carrier (b); and load deflection and durability cycling tests on the air spring (c) and (d).

cating machine which reproduces the intricate contours of the exact wooden model on suitable pieces of metal, called die blocks. The resulting dies are used to stamp out the panels for the body and related sheet metal assembly.

After release of the body and appearance sheet metal for tooling, the car Division outlines to top management all details of the proposed new car model program. When this program has been approved, the car Division then proceeds with the remaining tooling and other production plans.

Staff Engineers Responsible for Design of Specific Components

After final approval of the new car model program by top management, the car Division's staff engineers then assume responsibility for the final production design of their assigned parts. Meetings are held between the staff engineers (Fig. 7) during which time final mechanical specifications are studied, changes explained, and the scope and limitations of the design program tentatively mapped out. Engineering tests are then initiated to finalize the design of various components (Fig. 8).

The design responsibility of the staff engineers is based on functional assemblies rather than on arbitrary or structural sub-divisions of the automobile. The body, chassis, engine, carburetion, transmission, and electrical equipment and accessories are typical functional assemblies.

Where overlapping occurs, direct responsibility is given the staff engineer responsible for the proper functioning of the part and concurrent or advisory responsibility to the other staff engineers involved. The chassis engineer, for example, is given direct responsibility for the wheels and tires, but the body engineer has concurrent responsibility in providing clearance for them.

The staff engineer also assumes responsibility for a design schedule which will release engineering data at a date commensurate with the tooling time required for his parts. Where joint design responsibility for a part exists between the staff engineer and an outside supplier, the design schedules must be worked out with proper regard for the requirements of each.

During the course of his design work the staff engineer may call on the experimental engineering group for information

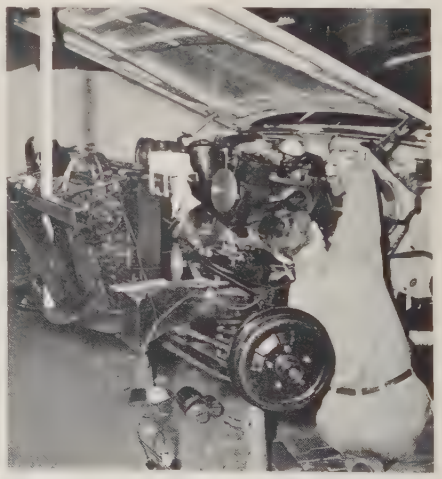

Fig. 9—As soon as parts were available, work was started on building the prototype cars.

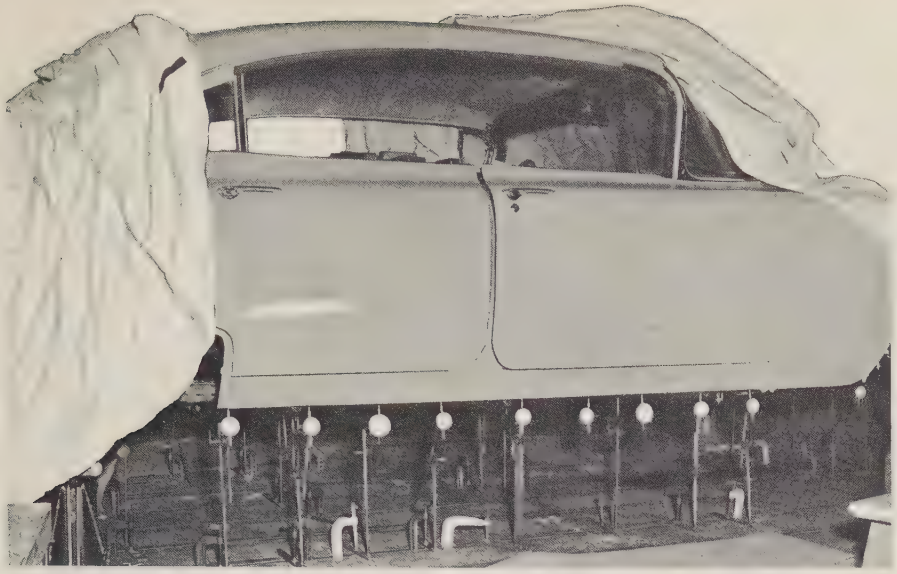

Fig. 10—Before the frame and body were assembled into a completed prototype car, additional structural tests were performed by Cadillac engineers. At this stage of development, the body was kept covered for security.

relating to the results of tests performed on certain mechanical components which have been under continuous development. Such information may be essential to the staff engineer in the logical development of his program. If deemed necessary, a test program will be arranged in which current model cars are modified to include the particular component to be tested. The modified cars are then sent on a road trip[3] to test the component or components under extremes of actual operating conditions.

Prototype Cars Tested at Proving Grounds

Shortly after parts have been released for tooling, the model shop begins to produce parts by hand methods for use in building prototype cars (Fig. 9). One or more prototype cars are built for each chassis and typical body type. Each body and chassis assembly is static tested in bending and torsion before being built into a completed prototype car (Fig. 10).

As each prototype car is finished it is subjected to complete performance tests at the GM Proving Grounds (Fig. 11). The prototype car also is used for appraisal and further refinement of those characteristics which cannot be measured by test equipment, but which are of vital importance in obtaining customer approval.

As tooling enters the tryout stage, completed production parts are assembled into a mock-up chassis (Fig. 12). This serves as an overall check on both tools and inspection fixtures. When tools for certain operations are incomplete, hand operations are sometimes substituted to obtain parts for a final check on the operations already tooled.

During this stage, methods and standards engineers, who have followed the progress of the new car model for many months, are called in to make their final studies to verify that manufacturing processes and facilities already planned are satisfactory. Those responsible for the assembly of the new model also disassemble and re-assemble the mock-up to train supervisory personnel and to verify that the model can be assembled easily. The service department also studies the mock-up for service accessibility and gathers final information for service procedures.

The changes resulting from these studies are the last stages in the actual design engineering program, and the mock-up is followed very carefully since it really checks or proves the design.

Final Stages Keyed to Announcement Date

Of major concern in planning the development of the annual new car model is the announcement date—the day the new model is to make its first appearance in dealer showrooms. The announcement date fixes the number of weeks and days required to build a sufficient number of cars to supply dealers. This, in turn, establishes a date for the start of production.

The start of production date is used to back off the number of months, weeks, and days for die tryout, for tooling try-

Fig. 11—At the GM Proving Grounds, the prototype test cars were subjected to numerous severe durability tests. Such tests included highway cruise performance on the multi-speed test track (a); ride and handling on the Block road (b); and performance on the 16 per cent grade hill (c).

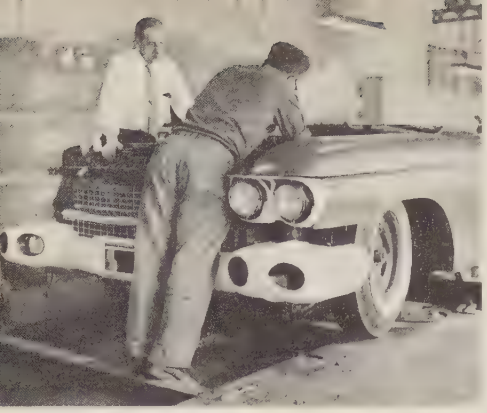

Fig. 12—The mock-up chassis, shown here under construction, served many purposes. For example, it served as an overall check on tools and inspection fixtures; provided information on assembly procedures; and allowed the service department to gather information on service accessibility and service procedures.

out, and for pilot assembly operations. These operations are necessary for assurance that all parts will assemble in proper sequence with a minimum of effort and time. The start of production date is the point at which tooling and any plant rearrangement must be completed. Every operation preceding this date is pinpointed upon it.

More than one year's work goes into preparation for new car model production. When does this preparation begin? The first step takes place during the engineering design of the new model. Close coordination with engineering is the first job of production so that the final design is one which can be manufactured efficiently.

The production activity reaches high gear when engineering hands over to manufacturing engineers several acres of drawings and parts lists. It is at this point that departments such as standards, cost, master mechanic, purchasing, metallurgy, process, production control, accounting, and assembly begin to coordinate their activities and talents toward the final goal of producing the new car model. These departments function to provide the skillful combination of men, methods, machines, and materials necessary for the successful production of the new car model.

As the day nears for the start of production, materials from fabricating plants and outside suppliers begin to converge for use on the final assembly line. As soon as the last car of the current model rolls off the assembly line, work is started immediately to make ready for the new model. Old equipment is removed and new tooling rushed in. Almost overnight the assembly line undergoes the transformation necessary for production of the new model.

At last the results of over three years planning and developmental work are realized when assembly begins and the new car models are made ready for shipment (Fig. 13).

Summary

The development of the annual new car model is not a simple process. It is a process which requires much time and extensive preparation because of its complexity. Careful planning and coordination are required to make certain that the developmental program proceeds without delay.

The realization of the annual new car model is not the result of the genius of one man or any one group of men. Rather, it is the result of close teamwork between many groups of men having a wide diversity of talents. All contribute their share of knowledge. All work toward a common goal.

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Sherwood, J. M., and Williams, R. R., "Some Typical Processing Problems Resulting From an Annual Model Change," *General Motors Engineering Journal*, Vol. 4, No. 2 (April-May-June 1957), pp. 22-27.

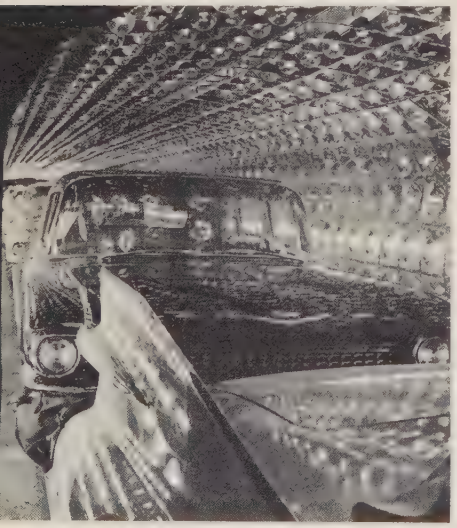
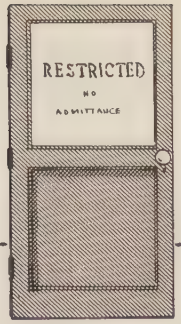


Fig. 13—Three years of developmental work were realized when the 1959 Cadillac entered production and the first models were shipped to dealers.

Confidential Relationships



By SIDNEY CARTER
Patent Section
Detroit Office

Some problems and some safeguards when dealing with technical information

THE practice of patent law by the corporate patent department may be viewed broadly as the practice of law for the purpose of avoiding legal difficulties and for ensuring the free competitive development and expansion of the company's activities. These purposes are achieved only by constant awareness of problem situations and the wholehearted cooperation between operating personnel and the patent department.

One such situation is the offer by suppliers and by private individuals outside the company of inventions, designs, ideas or other information. From the standpoint of good public relations and improvement and broadening of operations, the company should welcome the submission of such intelligence. However, it must always be alert to avoid limitation of its freedom of action and assumption of legal liabilities by such participation. An analysis of the problem will reveal the necessity for and the general nature of the guide rules necessary to maintain unhampered operations and freedom from serious and expensive litigation.

The right of an originator to exclude others from the use of his invention, design, writing, or idea was recognized in the law before the development of any patent and copyright system. The courts acknowledged that such intellectual works could be protected by an express agreement between the parties to receive the information as a trade secret or in confidence, that is, with the right to use the information in only a specified manner and/or under specified conditions. In the absence of an express agreement, it was comparatively easy for the courts to take the next step and find that the circumstances were such as to create an implied agreement of confidential relationship between the parties. Further, in the absence of either an express or implied agreement, the courts in the last five decades have shown an increasing tendency to apply broad concepts of justice or ethical reasoning to conclude that there is unjust enrichment, that is, that the circumstances of disclosure by the inventor or author imply an obligation not to use or further disclose without compensation.

Application of the Law

The recognition of exclusive rights by express contract ordinarily presents only straightforward questions of law and fact and is thus most clearly determinative of the rights and liabilities of the submitter and the recipient company. Clearly then, such agreements must be entered into only after due consideration by qualified and authorized company personnel. However, most submission problems arise not by reason of the existence of an express contract but rather from circumstances in which the judge or the jury finds either implied contract or unjust enrichment. Such cases are decided on their particular circumstances and according to the inferences, including the character of the litigants, the equities and obligations resulting from the facts, and in the light of the applicable law.

While there is much conflict of law in submission cases, certain conclusions may be drawn. A receiver will be liable for damages if his actions or statements either directly, indirectly, or by reasonable inference, may be taken as a promise to pay for the suggestion, or treat the information as confidential. Even in the absence of such implied agreement liability may arise on the basis of unjust enrichment. The circumstances that constitute such an agreement may be very broad. The subject matter of the submission need not be patentable or copyrightable; it may even be within the public knowledge provided it was new and valuable to the receiver and was used by him as a result of the submission.

The following are some typical cases of the kind referred to.

Case A:

Plaintiff designed a transparent candy wrapper, developed a machine for making the wrapper and disclosed the machine to defendant who wished to manufacture the wrapper. Defendant had agreed to keep the machine a secret and had agreed to pay for the right to manufacture but, upon finding and purchasing a patent owned by a third party covering the machine, refused to pay plaintiff. The court found for the plaintiff on the basis of confidential disclosure.

Case B:

After a prolonged period of negotiation and close working between the plaintiff and defendant for license rights under a patent application covering an automatic fire check in gas controls, the defendant used plaintiff's novel invention before the patent issued but did not compensate him. The court awarded plaintiff damages on the basis that such use was a breach of confidence and unjust enrichment.

Case C:

In another case the court found a confidential relationship where, at the request of the defendant, the plaintiff spent much time and effort and prepared many drawings in disclosing to the defendant his idea for a shipping container.

Case D:

The use of a legend on drawings submitted in response to an invitation to bid was held to effect a confidential agreement between the parties where the plaintiff's bid was rejected and parts of his system used. The legend declared the drawings to be the plaintiff's property and for use as a reference only.

Case E:

It has also been held by the court that a confidential relationship existed where the plaintiff submitted a copy of his pending patent application to defendant

who turned down the submission, damages being awarded plaintiff on the basis of defendant's subsequent use of a structure having a broad function similar to that covered by plaintiff's application, although the structural combination and operating principles were different. The facts showed that plaintiff had widely advertised his ideas both by word-of-mouth and by distribution of copies of his application.

Problems Posed by Confidential Relationships

It is thus apparent that dealings on a confidential basis make the recipient company vulnerable to litigation in an area of nebulous legal rights and liabilities. The following are examples of specific problems that may arise from such relationships:

- The disclosed subject matter may be related to current research programs thus tending to increase chances of litigation
- Reassignment of personnel is made difficult since it is impossible for those having knowledge of the submitted information to keep the data entirely separate in their minds from all other information
- Rights to use information available freely to others would be lost because of the first acquisition from the submitter
- Obligations to the submitter could continue indefinitely thus seriously limiting the recipient's scope of operations
- Since the scope and nature of unpatented information is generally extremely broad and indefinite, the recipient's obligations and liabilities are correspondingly broad and indefinite.

Conclusions

Various safeguards have been adopted by different companies in order that they be free to operate without danger of expensive and vexatious litigation on the basis of breach of confidence.

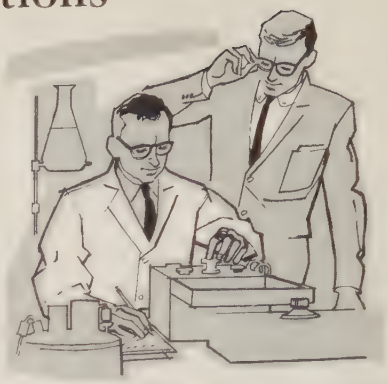
Many companies refuse to consider disclosures unless an agreement has been entered into whereby the submitter waives all claim of confidential relationship. In some instances such submission agreements include provisions whereby the parties agree that the recipient's liability shall be only to the extent that the subject matter disclosed is covered by a valid patent owned by the submitter.

Similarly, many companies have issued instructions to their personnel covering procedures to be followed in regard to contacts by or with persons other than fellow employes in order to avoid accepting any information, devices, or materials under circumstances which expressly or impliedly create a confidential relationship. Such situations could arise where the technical information or drawings are marked confidential or proprietary or with limitations on disclosure or use, where the items are verbally stated to be confidential, or where the information is in the form of a patent application.

Also, many companies have adopted procedures whereby all contracts, purchase orders, or other agreements purporting to commit the company not to use inventions, drawings, or other technical information except under specified conditions or for limited purposes or identifying such information as confidential or proprietary are submitted to management before acceptance. Similar procedures are frequently adopted as to all drawings or other technical information marked as confidential, proprietary or purporting to place limitations on disclosure or use of such materials.

In view of the serious nature of the problems relating to confidential disclosures and in view of the differences in approach to such problems adopted by various companies, it is recommended that all personnel, including sales, purchasing, or engineering personnel, acquaint themselves with their company's policies in this area. After such familiarization, it remains the responsibility of each employe to be ever mindful of such problems in connection with his relations with others than his fellow employes.

Notes About Inventions and Inventors



Contributed by

Patent Section

Detroit Office

The following is a general listing of patents granted in the names of General Motors employes during the period January 1, 1959 to March 31, 1959.

AC Spark Plug Division Flint, Michigan

• **Robert W. Smith,** (*B.S. in physics, University of Chattanooga, 1929 and Ph.D. in physics, University of Michigan, 1933*) staff scientist, inventor in patent 2,867,683 for a high energy electrical lead-in.

• **Carl F. Schaefer,** (*B.S.Cer.E., University of Illinois, 1939*) supervisor, ceramic development and control, and **Karl Schwartzwalder,** (*B.Cer.E., 1930 and M.S. 1931, The Ohio State University*) director of research, Ceramic Laboratory, inventors in patent 2,867,888 for a method of firing alumina ceramics.

• **John D. McMichael,** (*Michigan State University*) product engineer, inventor in patent 2,869,679 for a cleaner silencer assembly.

• **Paul N. Beauchamp,** (*B.S. in mining engineering, 1938 and B.S.E.E., 1947, Michigan College of Mining and Technology*) project engineer, inventor in patent 2,869,917 for an extractor.

• **Richard L. Comer,** (*B.S.Cer.E., University of Illinois, 1952*) ceramic engineer, inventor in patent 2,870,233 for a thermocouple.

• **Michael Skunda,** supervisor, spark plug production engineering, inventor in patent 2,871,389 for a spark plug and method for improving leakage characteristics thereof.

• **Gordon W. Harry,** (*B.S.M.E., University of Michigan, 1923*) staff engineer, inventor in patent 2,873,686 for an oscillatable diaphragm pump.

• **Gordon B. Elder,** (*B.S.Aero.E., University of Michigan, 1937*) staff engineer, inventor in patent 2,873,688 for a pump with oblique pulsator diaphragm.

• **Joseph Zubaty,** (*M.S.M.E., University of Prague, 1918*) staff engineer—special assignment, inventor in patent 2,873,956 for a fuel injection control valve.

• **Roy L. Bowers,** (*B.S., Michigan State University, 1930*) staff engineer, and Gerald W. Colby, no longer with GM, inventors in patent 2,874,206 for sealed electrical terminals.

• **Earl W. Pierce,** (*B.S.M.E., University of Michigan, 1939*) senior project engineer, inventor in patents 2,874,208 and 2,875,365 for a spark plug and a spark plug and method of manufacturing same, respectively.

• **Raymond E. Summerer,** (*B.S.E.E., University of Colorado, 1951*) senior project engineer, inventor in patent 2,874,321 for an igniter plug.

• **Wilfred A. Bychinsky,** (*B.S.E.E., 1930; M.S.E., 1931; and Ph.D., 1933, University of Michigan*) chief engineer, automotive products, inventor in patent 2,874,322 for a low tension spark plug.

• **Wilfred A. Bychinsky* and Alfred Candelise,** (*Ph.D. in electrical-mechanical engineering, University of Naples, 1923*) staff engineer, inventors in patent 2,874,323 for a spark plug.

• **Jesse E. Eshbaugh,** (*M.E., University of Cincinnati, 1923*) staff engineer, inventor in patent 2,874,712 for tank vent structures.

• **Norman D. Lawless,** (*B.S.E.E., Michigan State University*) process engineer; **Howard L. Roat,** (*General Motors Institute*) manufacturing manager; and **Roscoe M. Wheeler,** automotive engineer, inventors in patent 2,875,407 for an electrical instrument of the differential galvanometer type.

• **Robert B. Gelenius,** (*E.E., Michigan State University, 1950*) project engineer, and **Robert E. Resseguie,** (*B.S.M.E., Michigan State University, 1951*) project engineer, inventors in patent 2,875,634 for electrical and hydraulic transmission control systems.

***Inventors' names marked with an asterisk have biographical listings noted previously in this issue's Notes About Inventions and Inventors.**

• **James A. Norton,** (*Associate in Science degree, Flint Junior College, 1934; S.B. degree, 1936; and Ph.D. in organic chemistry, 1939; University of Chicago*) research scientist, inventor in patent 2,875,899 for an oil filter coating.

• **Homer R. Hastings,** (*B.S.E.E., Michigan State University, 1939*) staff engineer, inventor in patent 2,877,327 for a variable resistor sending unit for gages.

Allison Division
Indianapolis, Indiana

• **Kenneth O. Johnson,** (*B.S.Aero.E., Purdue University, 1950*) senior project engineer, inventor in patent 2,867,460 for a turbine rotor assembly.

• **Arthur W. Gaubatz,** (*B.S., University of Wisconsin, 1920*) senior project engineer, inventor in patent 2,870,632 for a heated pressure probe; in patent 2,871,829 for a servo-motor with floating control linkage; and in patent 2,874,926 for a compressor air bleed-off.

• **William R. Harding,** (*General Motors Institute, 1946*) supervisor, production control systems, and **Charles J. McDowall,** (*B.S.M.E., University of Florida, 1927*) technical assistant to the director of engineering, inventors in patent 2,870,633 for a heated pressure probe.

• **Herman B. C. Dhonau,** (*M.E., Stevens Institute of Technology, 1930*) senior project engineer, and **Stanley E. Nelson,** (*B.S.M.E., University of Wisconsin, 1939*) chief, power section, inventors in patent 2,870,956 for an air intake control apparatus.

• **Theodore O. Wiese,** (*University of Wisconsin Extension*) senior layout man, and Stuart Wilder, Jr., no longer with GM, inventors in patent 2,873,944 for a turbine blade cooling.

• **Dimitrius Gerdan,** (*B.S.M.E. and B.S.I.E., University of Michigan, 1932*) director of engineering, Aircraft Engineering Department, and **Charles J. McDowall***, inventors in patent 2,875,579 for a gas turbine engine midframe.

• **Earl J. Clark,** (*B.S.M.E., Purdue University, 1941*) head, Engineering Section, Bearing Department, inventor in patent 2,877,067 for a bearing lubricator assembly.

• **John H. Ellis,** (*M.E., University of California, 1940 and Ch.E., University of Denver, 1950*) project engineer, inventor in patent 2,879,117 for a piston ring expander.

Aeroproducts Operations
Allison Division
Vandalia, Ohio

• **Howard M. Geyer,** (*B.S.I.E., University of Alabama, 1940*) chief research engineer, inventor in patents 2,869,385 and 2,874,579 for a means for interconnecting control surfaces and a high temperature hydraulic actuator, respectively.

• **Darrell E. Royer,** (*Sinclair College and University of Dayton*) senior designer, inventor in patent 2,869,564 for a governor valve assembly.

• **Virgil B. Battenberg,** (*M.E., University of Dayton, 1958*) senior project engineer; **Robert L. Sayre,** (*B.S.M.E., Carnegie Institute of Technology, 1943*) head, Design Section; and Fred H. Katterheinrich, no longer with GM, inventors in patent 2,874,787 for an air driven power unit.

• **Alan B. Blackburn,** (*Marietta College and The Ohio State University*) experimental engineer; James R. Kessler, no longer with GM; **Robert K. Skinner,** (*B.S.E.E., University of Cincinnati, 1943*) senior project engineer; and **John H. Smith,** (*B.S.M.E., University of Michigan, 1949*) senior project engineer, inventors in patent 2,876,847 for an air driven propeller therefor.

• **Richard A. Hirsch,** (*University of Dayton and Sinclair College*) head, Electra Propellers Section, and Harold H. Detamore, no longer with GM, inventors in patent 2,876,848 for a propeller mechanism.

• **Howard M. Geyer*; Norman J. Bullock,** (*B.S.M.E., University of Cincinnati, 1950*) project engineer; and **James W. Light,** (*Miami University and The Ohio State University*) experimental engineer, inventors in patent 2,879,746 for an actuator with unidirectional locking means.

Buick Motor Division
Flint, Michigan

• **Oliver K. Kelley,** (*B.S., Chicago Technical College, 1925 and Massachusetts Institute of Technology*) chief engineer, inventor in

patent 2,875,643 for a transmission control system.

Cadillac Motor Car Division
Detroit, Michigan

• **Robert W. Burton,** (*General Motors Institute*) assistant staff engineer, and **Robert L. Nance,** (*B.S.M.E., Purdue University, 1950*) senior project engineer, inventors in patent 2,867,129 for a fluid power steering valve.

• **Charles F. Arnold,** (*B.S.M.E., University of Cincinnati, 1923*) chief engineer, and **Edward N. Cole,** (*General Motors Institute, 1933*) vice president and general manager, Chevrolet Motor Division, inventors in patent 2,870,362 for a pre-aimed light projector.

• **Robert T. Doughty,** (*B.M.E., Tri-State College, 1943*) senior project engineer, inventor in patent 2,871,836 for an engine cooling system with radiator by-pass.

• **Casimer J. Cislo,** (*Wayne State University and University of Michigan*) senior project engineer, inventor in patent 2,872,206 for an independent dirigible wheel suspension.

Central Foundry Division
Saginaw, Michigan

• **Milton J. Diamond,** (*B.E.E., University of Detroit, 1932*) research engineer, inventor in patent 2,876,638 for an electronic flaw detector.

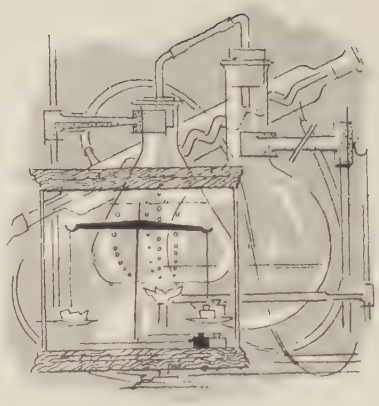
Chevrolet Motor Division
Detroit, Michigan

• **John L. Hickey,** (*General Motors Institute, 1941*) resident product engineer, Toledo, Ohio, transmission plant, and **William G. Wallace,** (*Purdue University*) product engineer, Toledo, Ohio, transmission plant, inventors in patent 2,868,036 for transmission control systems.

• **Paul J. Loisell,** process man, Flint, Michigan, manufacturing plant, inventor in patent 2,868,582 for a material handling device.

• **Robert C. Anthony,** design engineer, and **Robert J. Williams,** senior project engineer, inventors in patent 2,870,477 for a hinge.

These patent listings are informative only and are not intended to define the coverage which is determined by the claims of each one.



• **Jerry R. Mrlik,** (*Akron University; Cleveland Engineering Institute; and Fenn College*) design engineer, and **Frank J. Winchell,** (*Purdue University*) staff engineer in charge of chassis and components, inventors in patent 2,875,856 for a parking lock for transmission.

• **Robert Schilling,** (*M.E., Technical University, Munich, Germany, 1922*) director, Research and Development Department, inventor in patent 2,873,616 for an adjustable control mechanism.

Delco Appliance Division
Rochester, New York

• **Gordon H. Diehl,** (*B.M.E., General Motors Institute, 1953*) application heating and air conditioning engineer, inventor in patent 2,871,847 for a counter-flow warm air furnace.

• **Cyril T. Wallis,** (*Technical School, Cambridge, England*) patent and new devices contact, and Henry C. Rohr, retired, inventors in patent 2,874,770 for a self-supporting blind.

• **Eugene R. Ziegler,** (*B.E.E., University of Rochester, 1943*) design engineer, inventor in patent 2,878,505 for a windshield cleaning system.

Delco Products Division
Dayton, Ohio

• **Mearick Funkhouser,** (*M.E., Cornell University, 1932*) chief engineer, and **Harold E. Schultze,** project engineer, inventors in patent 2,869,685 for an inertia controlled shock absorber system.

Delco Radio Division
Kokomo, Indiana

• **James H. Guyton,** (*B.S.E.E., 1934 and M.S.E.E., 1935, Washington University*) chief engineer—radio, and Edward G. Roka, deceased, inventors in patent 2,874,233 for a transistor power amplifier.

Delco-Remy Division
Anderson, Indiana

• **Lyman A. Rice,** (*B.S.E.E., University of Utah, 1935 and M.S.E., University of Michigan, 1936*) staff engineer, inventor in patent 2,867,702 for a switch.

• **Thomas C. Heath,** (*E.E. and M.E., Tri-State College*) regulator and relay engineer, inventor in patent 2,869,051 for an electric regulator.

• **John E. Antonidis,** (*Purdue University*) section engineer; **Merrill E. Dray,** checker, Drafting Department; and **Robert A. Ulm,** (*International Correspondence School*) senior checker, Drafting Department, inventors in patent 2,870,354 for a dynamo electric machine.

• **Louis J. Raver,** (*B.S.M.E., Purdue University, 1947*) senior project engineer, inventor in patent 2,871,708 for a starting apparatus for internal combustion engines.

• **Garth A. Rowls,** (*B.S.M.E., Purdue University, 1932*) product engineer, and **Don G. Townsend,** (*B.S.Met.E., University of Illinois, 1953*) engineer—process, inventors in patent 2,872,499 for a vent plug and method of using same.

• **Julius H. Bolles,** (*B.S. in physics, Ohio Wesleyan University, 1920*) director of product reliability; **Lyman A. Rice***; and **Paul L. Schneider,** (*B.M.E., The Ohio State University, 1921*) special assignment, inventors in patent 2,858,497 for a battery charging circuit.

• **Herman L. Hartzell,** (*B.E.E., The Ohio State University, 1924*) chief engineer; **David C. Redick,** (*General Motors Institute, 1939*) section head, switches and horns; and **Clarence L. Julian,** senior project engineer, inventors in patent 2,872,537 for a distributor structure.

• **John R. Wirt,** (*B.S.E.E., Purdue University, 1930*) welding engineer, inventor in patent 2,878,552 for a laminated article and method of manufacture.

• **Brooks H. Short,** (*B.S.E.E., 1931 and M.S.E.E., 1934, Purdue University*) director, Advance Engineering; **Lewis R. Hetzler,** (*B.S.E.E., University of Michigan, 1941*) director, Applied Science Depart-

ment; and **John H. Falge,** (*B.S.M.E., Purdue University, 1946*) research engineer, inventors in patent 2,879,352 for a control device.

Detroit Diesel Engine Division
Detroit, Michigan

• **Joseph F. Voss,** (*Lawrence Institute of Technology*) senior designer, and Harold H. Albinson, retired, inventors in patent 2,867,136 for a transmission.

• **Carl S. Hoffman,** (*B.S.M.E., Wayne State University, 1952*) senior project engineer, inventor in patent 2,869,670 for an intake silencer.

• **Henry V. Shaw,** (*B.S.E.E., Pennsylvania State University, 1937*) senior engineer, inventor in patent 2,871,439 for an induction generator power system.

• **John Dickson,** (*diploma, Royal Technical College, Glasgow, Scotland*) staff engineer in charge of forward design, inventor in patent 2,873,575 for an intake and exhaust manifold system.

Detroit Transmission Division
Ypsilanti, Michigan

• **Walter B. Herndon,** (*B.S.E., State College of Washington, 1928 and M.S.E., University of Michigan, 1930*) director of engineering and sales, and **Darrel R. Sand,** (*B.M.E., General Motors Institute, 1949*) assistant staff engineer, inventors in patent 2,872,000 for a transmission and brake control system.

• **Walter B. Herndon*,** inventor in patents 2,875,699 and 2,876,656 for a variable capacity pressure system for transmissions and controlled coupling multistep automatic transmissions, respectively.

• **Alex Hardy,** (*General Motors Institute*) senior designer, inventor in patent 2,875,700 for an automatic transmission pump.

Diesel Equipment Division
Grand Rapids, Michigan

• **Lee T. Mekkes,** (*B.M.E., General Motors Institute, 1957*) junior engineer, inventor in patent 2,871,839 for a self-contained hydraulic lash adjuster.

• **Louis J. Van Slooten,** experimental engineer, inventor in patent 2,873,729 for a self-contained type of hydraulic valve lifter.

• **William A. Fletcher,** (*General Motors Institute, 1930*) director, manufacturing facilities and services, inventor in patent 2,873,788 for a filament coiling machine.

Electro-Motive Division
La Grange, Illinois

• **Swen W. Neilson,** project engineer, and Corless B. Nelson and John M. Smidl, no longer with GM, inventors in patent 2,869,336 for a refrigerating apparatus.

• **Kenneth D. Swander, Jr.,** (*B.S.M.E., Purdue University, 1942*) assistant air brake engineer, inventor in patent 2,871,063 for a brake system.

• **Bert H. Hefner,** electrical engineer, inventor in patent 2,872,141 for a cable hanger.

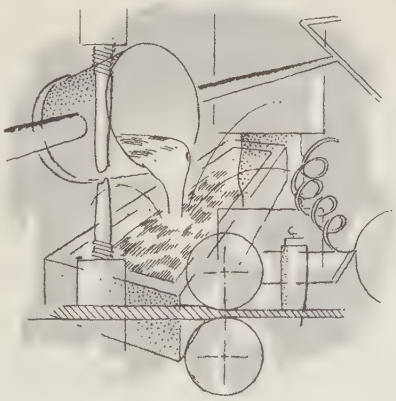
• **William F. Holin,** (*M.E., Konstanz, Germany*) senior project engineer, inventor in patents 2,874,646 and 2,878,760 for a railway vehicle suspension and a railway vehicle truck, respectively.

GM Engineering Staff
Detroit, Michigan

• **Richard P. Barnard,** (*B.S.M.E., University of Michigan, 1947 and bachelor of law degree, George Washington University, 1950*) patent attorney, Patent Section, inventor in patent 2,871,335 for a cigar lighter having retractable sleeve.

• **John Zimmerman,** (*Detroit City College*) senior design engineer, inventor in patent 2,871,846 for a pump.

• **Maurice A. Thorne,** (*B.A., George Washington University and University of Maryland*) engineer in charge, Vehicle Development Section, inventor in patent 2,873,953 for an air heating and cooling apparatus for vehicles.



• **William H. Kolbe,** (*B.S.M.E., University of Michigan, 1950*) senior project engineer, and John Dolza, no longer with GM, inventors in patents 2,877,002 and 2,878,798 for a fuel injection system and a split engine, respectively.

• **Alexander J. Sagady,** (*B.S.M.E., Detroit Institute of Technology, 1945*) senior design engineer, and John Dolza*, inventors in patent 2,879,046 for a fuel distributing valve for fuel injection system.

Euclid Division
Cleveland, Ohio

• **Anton Z. Panasewicz,** (*Fenn College, 1951*) layout man, inventor in patent 2,868,579 for a push plate assembly.

• **Edwin J. Selyem,** (*Fenn College and Case Institute of Technology*) now senior designer, Cleveland, Ohio, Ordnance Plant, Cadillac Motor Car Division, and **Russell C. Williams,** (*B.S.M.E., University of Illinois, 1932*) manager, research and test, inventors in patent 2,875,535 for a bulldozer.

• **Edwin J. Selyem*,** inventor in patent 2,876,877 for an automatic throttle control.

• **Russell C. Williams*,** inventor in patent 2,877,059 for a track roller.

• **Ralph J. Bernotas,** (*B.S.M.E. and M.S.M.E., Case Institute of Technology, 1954*) senior designer, inventor in patent 2,878,882 for a leg type traction means.

Fisher Body Division
Detroit, Michigan

• **Frank M. Gibson,** senior project engineer, inventor in patent 2,867,473 for a vehicle body panel sealing means.

• **Bernard J. Becker, Jr., and Jean Roger Duclos,** (*University of Detroit*) senior designers, inventors in patent 2,869,912 for a connector assembly for a door handle.

• **James H. Wernig,** (*Johnson School of Body Design and Engineering and Alexander Hamilton Institute*) general director of engineering and related activities, inventor in patent 2,871,501 for a windshield wiper.

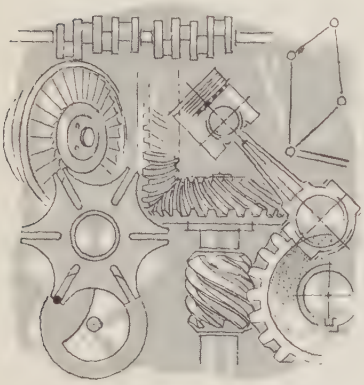
• **James D. Leslie,** (*B.M.E., University of Detroit, 1939*) engineer in charge, Mechanical Department, and **Henry J. Wubbe,** layout draftsman, inventors in patent 2,873,794 for an inertia latch.

Engelbert A. Meyer, senior project engineer, inventor in patent 2,875,493 for a clip assembly.

• **James D. Leslie***, inventor in patent 2,877,043 for a rotary bolt door latch.

Frigidaire Division
Dayton, Ohio

• **Edward C. Simmons,** (*University of Dayton*) senior engineer, inventor in patent 2,867,093 for a defrosting arrangement for refrigerating system.



• **Charles C. Whistler, Jr.,** (*B.S.M.E., Purdue University, 1944*) senior project engineer, inventor in patent 2,869,222 for a refrigerating apparatus.

• **Byron L. Brucken,** (*B.S., University of Dayton, 1956*) senior project engineer, inventor in patents 2,869,346 and 2,878,662 for a domestic appliance for washing, drying, and fluffing clothes and for a wobble mechanism for fluffing clothes in a domestic appliance, respectively.

• **Orson V. Saunders,** supervisor, major products, inventor in patent 2,869,952 for a door latch.

• **Keith K. Kesling,** (*University of Dayton and Dayton Art Institute*) project and design engineer, inventor in patent 2,869,954 for a domestic appliance; in patent 2,869,959 for a door mounting; and in patent 2,879,370 for a domestic appliance.

• **Kenneth O. Sisson,** (*B.S.M.E., South Dakota State College, 1936*) senior project engineer, inventor in patent 2,870,834 for a two-speed timer.

• **Edwin J. Miller,** (*B.S., Allegheny College, 1950 and M.S., University of Delaware, 1952*) physicist, and **Keith K. Kesling***, inventors in patent 2,871,676 for a refrigerating apparatus with magnetic latch.

• **Verlos G. Sharpe,** (*B.S.M.E., Purdue University, 1948*) section engineer, and **Jost S. Sucro,** (*Technical Academy of Munich, Germany, 1944*) senior detailer, inventors in patent 2,874,553 for a freezing device.

• **Millard E. Fry,** (*B.S.M.E., University of Pittsburgh, 1931*) senior project engineer, inventor in patent 2,875,016 for a domestic appliance.

• **Kenneth A. Harnish,** (*B.S.Arch.E., University of Michigan, 1923*) senior layout man, inventor in patent 2,876,460 for a counter-top construction.

• **Byron L. Brucken*, and George B. Long,** (*B.S.E.E., Purdue University, 1937*) supervisor, major product line, inventors in patent 2,877,333 for a domestic appliance.

• **Charles E. Rembold,** (*General Motors Institute*) project engineer, inventor in patent 2,878,653 for a refrigerated display case.

• **Edmund F. Schweller,** assistant chief engineer, inventor in patent 2,878,655 for a refrigerating apparatus with condensate director.

• **George B. Long***, inventor in patent 2,879,763 for a domestic appliance.

GMC Truck and Coach Division
Pontiac, Michigan

• **Donald J. La Belle,** (*B.M.E., University of Detroit, 1939*) staff engineer, inventor in patent 2,874,956 for a leaf and air spring suspension.

• **Francis C. Fleck,** (*B.M.E., General Motors Institute, 1950*) project engineer, and **George Ralich,** (*B.S.M.E., Indiana Technical College, 1954*) senior project engineer, inventors in patent 2,875,635 for a power plant control mechanism.

• **John R. Brice,** draftsman, and Clifford H. Dixon, no longer with GM, inventors in patent 2,875,746 for an engine accessory support means.

• **Hans O. Schjolin,** (*B.S., Karlstad College, Sweden, 1920 and Polytechnical Institute, Mittweida, Germany, 1923*) advance design engineer, inventor in patent 2,878,691 for a transmission and control system.

Guide Lamp Division
Anderson, Indiana

• **Frank J. Rada,** (*B.S.Ch.E., University of Illinois, 1936*) director, facilities and services, and **Karl R. Bowman,** (*B.S.Ch.E., Michigan College of Mining and Technology, 1940*) senior process engineer, inventors in patent 2,870,902 for a conveyor belt structure.

• **Eugene G. Matkins,** (*B.M.E., General Motors Institute, 1952*) project engineer, inventor in patent 2,872,618 for a low voltage light sensitive control system.

• **William E. Thompson,** senior process engineer, and Henry C. Wiese, deceased, inventors in patent 2,876,331 for a welding apparatus.

• **Lyle N. Williams,** (*A.B.Ch., Indiana University, 1936*) senior project engineer, inventor in patent 2,876,340 for a lamp assembly and lens securing means.

• **Charles W. Miller,** (*Purdue University*) project engineer, inventor in patent 2,876,395 for a pulse actuated light controlled switching means.

Harrison Radiator Division
Lockport, New York

• **Ledra M. Lawton,** (*B.S.Ch., Syracuse University; M.S., University of Buffalo; and physical chemistry Ph.D., Johns Hopkins University, 1932*) chief chemist, inventor in patent 2,867,037 for a composition for soldering metal and method for using same.

• **Frank A. Disinger,** product designer, and **John W. Godfrey,** (*B.S.Ch., Canisuis College, 1935*) assistant chief engineer, inventors in patent 2,874,555 for an evaporator arrangement.

Hyatt Bearings Division
Harrison, New Jersey

• **Ralph A. Altson,** (*teacher's diploma, Regent Technical Institute, London, England, 1930*) chief design engineer, inventor in patent 2,878,083 for a journal box.

Inland Manufacturing Division
Dayton, Ohio

• **Cletus L. Moorman,** (*University of Dayton*) project engineer, and Ellwood R. Riesing, deceased, inventors in patent 2,867,457 for a fluid seal.

• **Max P. Baker,** (*A.B., Miami University, 1922*) project engineer, inventor in patents 2,869,585 and 2,879,901 for a flexible diaphragm and a ball joint assembly, respectively.

• **Allen L. Everitt,** (*M.S.M.E., Purdue University, 1931*) section engineer, inventor in patent 2,871,566 for a sight system for firearms.

• **Philip J. Berner,** (*M.E., Stevens Institute of Technology, 1927*) project engineer, inventor in patent 2,872,539 for a steering wheel.

• **Arthur J. Frei,** senior project engineer, inventor in patent 2,874,552 for a freezing device.

• **Russell J. Bush,** (*B.S.Ch.E., Purdue University, 1925*) project engineer, inventor in patent 2,878,535 for a sealing strip.

• **Stanley R. Prance,** (*Wayne State University, 1926*) chief metalurgist, and **Harry O. Waag,** head, Paint Laboratory, inventors in patent 2,878,659 for a refrigerating apparatus.

• **Allen L. Everitt*; James E. Frederick,** (*Sinclair University*) project engineer; and **Clarence A. Mayer, Jr.,** (*B.I.E., General Motors Institute, 1956*) junior engineer, inventors in patent 2,879,090 for a resilient mounting means for absorbing axial and lateral thrusts.

• **Allen L. Everitt*, and James E. Frederick*,** inventors in patent 2,880,027 for a resilient coupling for independently rotatable elements.

Moraine Products Division
Dayton, Ohio

• **Harold W. Schultz,** research engineer, and Edward J. Vosler, retired, inventors in patent 2,867,898 for a method of manufacturing a brake band.

• **Calvin J. Werner,** (*E.E., University of Cincinnati, 1930*) general manager, inventor in patent 2,873,826 for a brake cooling control.

• **Peter Mushovic,** (*B.S.Met.E., Missouri School of Mines and Metallurgy, 1944*) assistant superintendent, manufacturing and **Harold W. Schultz*,** inventors in patent 2,879,587 for a method for making composite stock.

• **Richard C. Rike,** (*General Motors Institute*) section engineer, inventor in patent 2,879,867 for a brake cooling system.

New Departure Division
Bristol, Connecticut

• **Leland D. Cobb,** (*E.E., Pratt Institute, 1928*) manager, Bearing Development and Contract Department, inventor in patents 2,870,890 and 2,872,219 for a one-way clutch and a demountable closure, respectively.

Oldsmobile Division
Lansing, Michigan

• **Gilbert Burrell,** (*B.S.E.E., Michigan State University, 1928*) motor engineer, inventor in patent 2,878,800 for a frusto conical combustion chamber and method of making same.

• **Charles L. Wagner,** service engineer, inventor in patent 2,879,047 for a fuel system.

GM Overseas Operations Division
New York, New York

• **Kenneth E. Buckman,** assistant chief engineer, No. 2 Plant, AC-Delco Division, and **Donald Bennion Browne,** (*Ackworth School and Smethwick Technical School*) director, No. 2 Plant, AC-Delco Division, GM Limited, London, England, inventors in patent 2,874,849 for a filter for filtration of fluids.

Packard Electric Division
Warren, Ohio

• **Robert C. Woofter,** (*Fenn College*) chief, Wiring Assemblies Design and Development Section, inventor in patent 2,874,-365 for a connector.

Pontiac Motor Division
Pontiac, Michigan

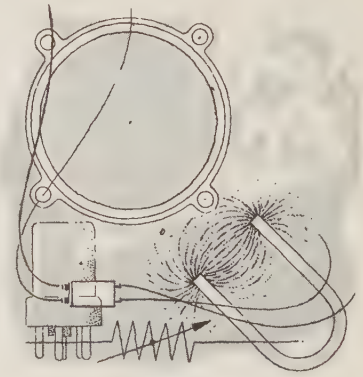
• **Francis H. Grady,** (*International Correspondence School*) transmission engineer, inventor in patent 2,869,506 for a transmission control indicator mechanism.

• **Kenneth M. Zemke,** (*B.S., University of Michigan, 1947 and The Ohio State University*) senior designer, inventor in patent 2,870,649 for a combined control for carburetor and transmission.

• **George W. Lampman,** (*International Correspondence School*) project engineer; **Clayton B. Leach,** (*A.B. in mathematics and chemistry, Park College, 1934 and General Motors Institute*) chassis engineer; and **Lloyd R. Vivian, Jr.,** (*M.E., Detroit Institute of Technology, 1939 and B.S.M.E., Yale University, 1943*) senior project engineer, inventors in patent 2,873,962 for a leaf spring assembly.

GM Research Laboratories
Detroit, Michigan

• **James C. Holzwarth,** (*B.S., 1945 and M.S., 1948, Purdue University*) supervisor, Metallurgical Engineering Department, and **Robert F. Thomson,** (*B.S.M.E., 1937; M.S.M.E., 1940; and Ph.D., 1941, University of Michigan*) head, Metallurgical Engineering Department, inventors in patent 2,867,531 for a corrosion resistant low alloy steel.



• **William F. King,** (*General Motors Institute, 1940 and B.S.M.E., University of Michigan, 1941*) assistant head, Special Problems Department, inventor in patents 2,867,699 and 2,872,819 for a switching device and an apparatus for compensating quadrature resolved unbalance components, respectively.

• **Raymond S. Amala,** (*B.S.Met.E., M.S.Met.E.; and B.S.Ch.E., Michigan, College of Mining and Technology, 1942*) supervisor, special molding, Metallurgical Engineering Department; **Robert F. Thomson*;** and **Charles M. Eberhardt,** (*Met.E., Michigan College of Mining and Technology, 1949*) now chief metallurgist

Danville, Illinois, plant, Central Foundry Division, inventors in patent 2,873,495 for a shell molding.

• **Arnold O. DeHart,** (*B.S.M.E., West Virginia University, 1950*) senior research engineer, inventor in patent 2,879,113 for a hydrostatic bearing.

• **Robert L. Dega,** (*B.M.E., General Motors Institute, 1948*) supervisor, Mechanical Development Department, inventor in patent 2,878,995 for a centrifuge for liquids.

Rochester Products Division
Rochester, New York

• **Richard J. Brunner,** (*Armour Institute and University of Michigan Extension School*) senior experimental engineer, inventor in patent 2,867,422 for a carburetor idling mechanism.

• **Charles E. Wing,** (*B.M.E., General Motors Institute, 1951*) now with Oldsmobile Division, inventor in patent 2,867,423 for an idle vent valve.

• **Elmer Olson,** (*Lewis Institute*) engineering consultant, and **Donald D. Stoltman,** (*B.S.M.E., Rensselaer Polytechnic Institute, 1947 and M.S. in automotive engineering, Cornell University, 1948*) senior project engineer, inventors in patent 2,868,520 for a dual carburetor control system.

• **Howard H. Dietrich,** (*B.S.E.E., Purdue University, 1926 and Yale University*) patents, new devices, and project analysis engineer, inventor in patent 2,868,521 for a degasser.

• **Lawrence C. Dermond,** (*Purdue University and Tri-State College*) staff engineer, inventor in patent 2,869,165 for a windshield cleaning apparatus; in patent 2,873,958 for a thermostatically controlled air bleed; and in patent 2,876,747 for a windshield wiper actuating mechanism.

• **Donald D. Stoltman*,** inventor in patent 2,871,001 for a throttle actuating mechanism.

• **Elmer Olson*,** inventor in patent 2,873,732 for a fuel induction system.

• **Clarence R. Lunn,** supervisor, Michigan area sales engineers, inventor in patent 2,873,957 for a carburetor float mechanism.

• **Willard H. Janneck,** (*B.S.Ch. and M.S.Ch., University of Rochester, 1940*) senior engineer; **Donald P. Worden,** process engineer in charge, Tubing Process Development Department; and Roger D. Young, no longer with GM, inventors in patent 2,876,132 for a process of coating steel tubing.

• **John M. Barr,** (*B.S.M.E., Rose Polytechnic Institute, 1925*) senior research engineer, inventor in patent 2,877,004 for a fuel induction system.

• **John B. Burnell,** (*Massachusetts Institute of Technology and General Motors Institute, 1941*) assistant chief engineer, Research and Development Department, and John Dolza, no longer with GM, inventors in patent 2,867,201 for a cylinder block.

• **Ronald C. Groves,** (*B.E.E., 1936 and B.M.E., 1937, Lawrence Institute of Technology*) staff engineer, inventor in patent 2,869,527 for a charge forming means for an internal combustion engine.

Saginaw Steering Gear Division
Saginaw, Michigan

• **David P. Smith,** (*Lawrence Institute of Technology and Michigan State University*) project engineer, inventor in patent 2,871,969 for a hydraulic power steering gear.

• **Douglas Gill,** designer, and **Jean V. Syring,** (*B.A. and M.A. in business administration, University of Michigan, 1949*) sales engineer, inventors in patent 2,875,630 for a mechanical movement device.

• **Jean V. Syring*,** inventor in patent 2,875,631 for a mechanical movement device.

• **David M. Gurney,** (*B.S.M.E. and B.S.A.E., Tri-State College, 1948*) project engineer, and **Marvin H. Wagner,** (*University of Illinois*) designer, inventors in patent 2,875,637 for a gear shift assembly.

• **Leonard R. Grabowski,** (*Bay City Junior College*) designer, inventor in patent 2,876,990 for a lifting jack.

• **Paul V. Wysong, Jr.,** (*University of Kansas*) sales supervisor, actuators, **Arthur F. Bohnhoff,** (*B.S.M.E., Michigan College of Mining and Technology, 1938*) senior designer; and Walter F. West, no longer with GM, inventors in patent 2,878,788 for an alternator valve assembly for reversible fluid pressure systems.

GM Styling Staff
Detroit, Michigan

• **Rudolph Potocnik,** chief engineer, Body Development Studio, inventor in patent 2,873,998 for an automobile rear end construction.

• **Delbert C. Probst,** (*Milliken University, 1922*) senior design engineer, inventor in patents 2,874,993 and 2,876,003 for a latch for pivoting seat and a window regulator, respectively.

• **Anthony J. Ingolia,** (*M.S. in product design, Illinois Institute of Technology, 1952*) senior designer, and **Robert F. McLean,** (*B.S.M.E., 1943 and professional degree in industrial design, 1948, California Institute of Technology*) executive in charge of styling, product analysis, and planning, inventors in patent 2,876,037 for a vehicle body shell.

Ternstedt Division
Detroit, Michigan

• **Bewley D. Priestman,** (*B.A. in engineering science, 1938 and M.A.M.E., 1942, University of Cambridge, England*) engineering group supervisor; **LaVerne B. Ragsdale,** (*University of Detroit; Franklin College; and B.S.M.E., Lawrence Institute of Technology, 1939*) staff engineer; **Stanley D. Cockburn,** senior designer, Fisher Body Division; and **James D. Leslie,** (*B.M.E., University of Detroit, 1939*) engineer in charge, Mechanical Department, Fisher Body Division, inventors in patent 2,871,049 for a rotary gear bolt door latch.

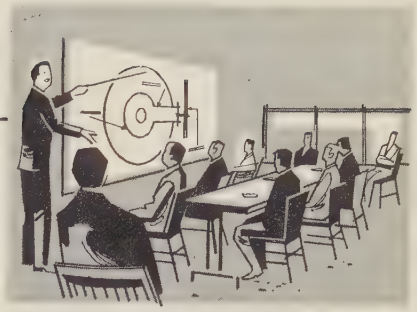
• **Mario J. DeDona,** (*M.E., Lawrence Institute of Technology, 1948*) senior project engineer, inventor in patent 2,873,470 for a hinge and hold-open.

• **Edward A. Schneidewind,** design engineer, inventor in patent 2,873,612 for a window regulator mechanism.

• **LaVerne B. Ragsdale*, and Akira Tanaka** ,(*B.S.M.E., Michigan State University, 1949*) group leader, design, inventors in patent 2,875,809 for a seat adjuster.

• **Barthold F. Meyer,** (*B.S.M.E., Pratt Institute, 1939 and Johns Hopkins University*) engineering group supervisor, inventor in patent 2,876,653 for a mechanical movement device.

Technical Presentations by GM Engineers and Scientists



The technical presentation is another way in which information about current engineering and scientific developments in General Motors can be made available to the public. A listing of speaking appearances by General Motors engineers and scientists, such as that given below, usually includes the presentation of papers before professional societies, lecturing to college engineering classes or student societies, and speaking to civic or governmental organizations. Educators who wish assistance in obtaining the services of GM engineers and scientists to speak to student groups may write to the Educational Relations Section, Public Relations Staff, General Motors Technical Center, P. O. Box 177, North End Station, Detroit 2, Michigan.

The following GM personnel made recent technical presentations.

Automotive Engineering

Max M. Roensch, assistant chief engineer, Experimental Tests Department, Chevrolet Motor Division, before the southern Wisconsin-northern Illinois section of the Society of Automotive Engineers, Beloit, Wisconsin, February 16; title: Chevrolet's New Engineering Laboratory.

Raymond A. Gallant, group head, instrumentation and electrical components, Engineering Laboratory, Chevrolet Motor Division, before the Niagara-Mohawk section of the Society for Experimental Stress Analysis, Schnectady, New York, February 19; title: Experimental Techniques in Automotive Development.

John O. Anderson, senior research engineer; **Charles W. Gadd,** supervisor, Special Problems Department, GM Research Laboratories; and C. H. Ek, no longer with GM, before the S.A.E. educational lecture series, Marquette University, February 20; title: Solving Automotive Engine Roughness Problems.

Gordon Hale, project engineer, AC Spark Plug Division, before pilots, mechanics, and aviation personnel of the Midland and El Paso, Texas, areas, February 25 and 26, respectively; title: Aircraft Spark Plugs.

Clare D. Harrington, administrative engineer, Oldsmobile Division, before the Lansing, Michigan, chapter of the American Society of Tool Engineers, March 9; title: Styling of a New Car.

S. T. Smith, supervisor, Engineering Services Department, Delco Appliance Division, before members of the Victor, New York, Lions Club, March 10; title: Automated Automobiles.

Zora Arkus-Duntov, staff engineer, Research and Development Department, Chevrolet Motor Division, before Corvettes of Massachusetts, Inc., Boston, March 3; title: Automobile Performance, and before the Detroit junior section of the S.A.E., March 11; title: Vehicle Handling and Stability, and Corvette Development.

Louis C. Lundstrom, director, GM Proving Grounds, before the annual meeting of the Texas Transportation Institute, College Station, March 12; title: Roadside Hazards and Full Scale Guardrail Impact Tests.

Kenneth Lehman, senior instructor, Product Engineering Department, General Motors Institute, before students of Bryant Junior High School, Flint, March 18; title: Auto Design.

Robert Lay, section manager, and **David Eddy,** section engineer, Spark Plug Engineering Department, AC Spark Plug Division, before dealers and marina operators of the Atlantic Refining Company, Alexandria Bay, New York, March 10; Latham, New York, March 11; Watkins Glen, New York, March 24; and Batavia, New York, March 25; title: Operation and Care of Marine Spark Plugs.

GM engineers who made presentations at the S.A.E. national passenger car, body, and materials meeting and the S.A.E. national production meeting, Detroit, March 16-20, were as follows: **Howard H. Kehrl,** staff engineer, Chevrolet Motor Division, title: Automatic Transmission Testing; **John Alden,** commercial vehicle engineer, GM Overseas Operations Division, Vauxhall Motors, Ltd., London, England, title: Design Features of European Trucks; **A. S. Bassette,** engineer in charge of Fisher Body Division proving ground activities, title: Electronic Testing of Body Mechanisms; **Walter E. Mitchell,** director, paint standards, Fisher Body Division, title: Acrylic Lacquers; **G. W. Jackson,** assistant chief engineer in charge of automotive and mechanical products, Delco Products Division, title: Fundamentals of the Direct Acting Shock Absorber; **Lloyd E. Muller,** director, Experimental Engineering Department, Buick Motor Division, title: Exhaust Systems—Fundamentals and Design Considerations; and **E. William Cummings,** supervisor, plant and methods engineering, Saginaw Steering Gear Division, title: Operations Planning at Saginaw Steering Gear.

Kenneth A. Stonex, assistant director, GM Proving Grounds, before the Legal and Highway Committee of the A.A.A., Washington D.C., March 13; title: Roadside Hazards; before University of Michigan auto mechanics and driver education teachers, Milford, March 14; title: Engineering and Safety Tests; before the annual conference of the Maine Highway Department, Augusta, March 24; title: Roadside Hazards and Full Scale Guardrail Impact Tests; and before Westchester County Highway Supervisors, White Plains, New York, April 1; title: Full Scale Guardrail Impact Tests.

The following Allison Division engineers made presentations at the S.A.E. national aeronautic meeting, New York City, April 1: **Max C. Hardin,** supervisor, fuels, and **H. D. Wilsted,** section chief, Research Engineering Department, title: Pyrophorics for Aircraft Propulsion—Their Promise and Problems; and **R. S. Hall,** chief, preliminary design engineer-

ing, Aircraft Engine Engineering Department, title: Design Approach to the Allison Model 250 Engine.

Rochester Products Division engineers who showed the Rochester Products film "Joe Period and the Carburetor" and discussed carburetor engineering were as follows: **Neil W. Carnell,** senior product engineer, before the Avon, New York, Lions Club, February 4; **Theodore H. Redman,** senior product engineer, before the Hilton, New York, "Carb-Kings," March 16; **Robert L. Barager,** junior sales engineer, before the Genesee Valley Timing Association, Rochester, New York, April 27; and **Theodore H. Redman,** and **Arthur Fandrey,** regional service engineer, before the United States Military Academy Ordnance Staff, West Point, New York, April 28.

Willard F. Speer, superintendent in charge of administration, Engineering Laboratory, Chevrolet Motor Division, before the University of Michigan Engineers Club, Ann Arbor, April 29: title; Chevrolet's New Engineering Laboratory.

Raymond E. Seekins, senior project engineer, Harrison Radiator Division, before the National Automotive Radiator Service Association, Philadelphia, Pennsylvania, May 1; title: Development of 196X Radiators.

Howard H. Kehrl, staff engineer, Chevrolet Motor Division, before the Williamsport, Pennsylvania, section of the S.A.E., May 4; title: Chevrolet's New Engineering Laboratory.

George A. Brown, field service engineer, AC Spark Plug Division, before the eighth annual Motor Vehicle Maintenance Conference, Seattle, Washington, April 22; title: Engine Tune-Ups, Electrical Systems, Shop Procedures, and Preventive Maintenance; before employes of the Puget Sound Auto Electric Company, Tacoma, Washington, April 26; title: Field Service Problems on Spark Plugs, Fuel Pumps, Oil Filters, and Air Cleaners; before the Automotive Maintenance Association, Flint, Michigan, May 14; title: The Spark Plug and You; and before parts and service dealers of Sidels-Chambers Company, Scottsbluff, Nebraska, May 4; Valentine, Nebraska, May 5; Alliance, Nebraska, May 6; and Chadron, Nebraska, May 7; title: the AC Product Service Clinic. Product Information, and Field Service Problems.

Stefan Habsburg, acting chief designer, Research Studio, GM Styling Staff, before the Bay City, Michigan, Industrial Management Club, May 14; title: The Design of Firebird III.

Donald J. La Belle, truck engineer, Truck Engineering Department, GMC Truck and Coach Division, before the American Transit Association Safety Supervisors Council, Oklahoma City, May 14; member of a panel discussing I.C.C. regulations.

Dale B. McCormick, section engineer, Automotive Ordnance Department, GM Engineering Staff, before the Combat and Tactical Vehicle Division, American Ordnance Association, Detroit, May 14; title: The Mobility and Reliability of Combat and Tactical Vehicles.

Emmet C. Moynihan, resident engineer, Production Engineering Department, Chevrolet Motor Division, before the Syracuse, New York, section of the S.A.E., May 15; title: A Carriage for Milady.

Diesel Engines

Elmer Bluhm, project engineer, Diesel Equipment Division, before the western Michigan section of the S.A.E., Muskegon, March 3; title: The General Motors Diesel Unit Fuel Injector.

John Dickson, staff engineer—forward design, Detroit Diesel Engine Division, before the Logging Convention, Seattle, Washington, March 24; title: New Concept in Diesel Engines.

B. B. Brownell, chief engineer, Electro-Motive Division, before Danville, Illinois, Engineers' and Industrial Clubs, April 8; title: Past, Present, and Future of Diesel Engines.

Charles E. Ervin, chief project engineer, Basic Engine Group, Detroit Diesel Engine Division, before the Baltimore, Maryland, section of the S.A.E., April 9; title: GM Diesel's Additional Engines—New Vees and In-lines.

Electrical Engineering

C. A. Rine, general superintendent—transistors, Delco Radio Division, before the Logansport, Indiana, Junior Chamber of Commerce, February 18; title: Transistor History, Materials, and Production Processes.

Robert E. Ellerby, assistant electrical engineer, GMC Truck and Coach Division, before the Maintenance Council of the North Carolina Motor Carrier's Association, Charlotte, February 24; title: Heavy Duty Electrical Equipment for Heavy Duty Trucks.

D. D. Riegleman, field service engineer, Delco Radio Division, before an electronics maintenance group, U. S. Marine Corps, Quantico, Virginia, March 10; title: Troubleshooting Transistor Circuits.

James Gregg, project engineer, Delco Radio Division, before the Kokomo, Indiana, Amateur Radio Club, March 17; title: TV Interference.

Robert W. Leland, electrical staff engineer, Delco Products Division, before the American Society of Heating, Ventilating, and Refrigerating engineers, Dayton, Ohio, March 17; title: Electric Motor Characteristics.

A. D. Rittmann, manager, device development, R and E Semiconductors Department, Delco Radio Division, before the Radio Engineering Society, Tri-State College, Angola, Indiana, March 30; title: Power Transistors, Present and Future.

Bert H. Hefner, electrical engineer, Electro-Motive Division, before the American Power Conference, Chicago, April 2; title: Automatic Plants for Peaking.

F. L. Hughes, supervisor, field service, Delco Radio Division, before an adult education electronics class, Anderson, Indiana, April 9; title: Transistor Fundamentals.

Thomas N. Schierloh, manager, Technical Service Department, Delco Products Division, before the National Industrial Service Association technical forum, Jacksonville, Florida, April 11; title: The Future of Fractional Horsepower Motor Repairs.

Ralph H. Bertsche, electrical engineer, GMC Truck and Coach Division, before the St. Louis, Missouri, section of the American Transit Association, April 22; title: Recent Developments in Regulators and Generators.

William Caldwell, field service engineer, Delco Radio Division, before the Foremen's Club Seminar, Kokomo, Indiana, May 11; title: Transistor Fundamentals.

Walter See, project engineer, Delco Radio Division, before the Foremen's Club Seminar, Kokomo, Indiana, May 18; title: Let's Talk About Stereo.

Foundry

Elmer E. Braun, works manager, Central Foundry Division, before the Quad City, Illinois, and the Saginaw, Michigan, chapters of the American Foundrymen's Society, March 16 and April 2, respectively; title: A New Approach to Marketing Castings.

Kenneth B. Valentine, metallurgical engineer, Pontiac Motor Division, panel member at Cleveland, Ohio, American Society for Metals meeting, April 6; discussion title: Castings, Forgings, and Stampings.

Guided Missiles

The following engineering personnel of AC Spark Plug Division's Milwaukee, Wisconsin, plant made recent presentations on guided missiles and inertial guidance systems.

Donald Dobransky, metallurgist, before the American Society for Metals, February 17; title: Missile Guidance Problems.

Clay Gibbs, executive engineer, missile guidance, before the Menomonee Falls, Wisconsin, Radio Amateur's Club, February 17; title: Missiles.

John R. Howard, test engineer, before the 27th Shock and Vibration Symposium, February 25; title: combined Environmental Tests of the Thor Guidance Section.

Bemrose Boyd, member, Advanced Design and Development Department, before students of Washington High School, March 3; title: Missiles—Problems of Space Flight.

G. B. Hardenbrook, section manager, before the Saginaw, Michigan, Exchange Club, March 17; title: Guided Missiles.

A. J. Italiano, administrative assistant, MACE Missile, before the Waukesha, Wisconsin, Masonic Temple, March 19; title: Missiles.

Robert Lessin, senior engineer, before engineering students of Marquette University, March 19; title: Inertial Guidance Applied Technology.

Robert Wright, head, Development Laboratories, before Air Explorer Scouts, Milwaukee, March 25; title: Missiles.

Harold Hogan, chief test engineer, before the First Reform Church Men's Club, Milwaukee, March 31; title: Missiles.

Jack Schmidt, senior project engineer, before students of Shorewood High School, February 23; title: Engineering for the Age of Space, and before the First Presbyterian Men's Club, April 1; title: Platform in the Sky.

James Bell, director, Navigation and Guidance Department, before the Michigan Patent Law Association, April 7; title: Missile Guidance.

Robert Ahrens, senior project engineer, before A. F. Gallun and Sons Supervisor's Club, April 8; title: Missiles.

Don Ziemer, senior project engineer, before the young adult group of the Our Saviour Lutheran Church, April 12; title: Thor Missile Guidance.

Herman Brandt, engineering material supervisor, before the Milwaukee Masonic, April 17; title: AC Spark Plug's and the Nation's Missile Program.

Tom O'Connell, TITAN project office head, before Fox Point and Bayside Grade Schools, April 21; title: Missiles and the Space Age.

Hans Hauser, MACE project office head, before administrator and teacher members of Phi Delta Kappa, Milwaukee, February 17; title: Why Inertial Guidance?, and before a group of young professional people, April 21; title: Missiles.

Lubrication and Bearings

Engineers of Hyatt Bearings Division who appeared before the southern New England section of the S.A.E., seminar series on antifriction bearings, March 10, were: **C. W. Kalchthaler,** chief engineer, title: Roller Bearings for Aircraft Engine Main Bearing Locations; **J. F. Moult,** assistant chief engineer—aircraft activities, title: Installation and Design Concepts; and **M. E. Otterbein,** manager, research and development, title: Development and Testing Programs.

Robert Guy, process engineer, Detroit Transmission Division, before the Detroit section of the American Society of Lubricating Engineers, March 31, member of "Stump-the-Expert" panel discussion group.

A. D. Edelman, assistant chief engineer, Product Design—Railroad, Hyatt Bearings Division, before the A.S.M.E.-A.I.E.E. Railroad Conference, Chicago, April 8; title: Load and Life Relationship of Roller Bearings as Applied to Railroad Journals.

John Panek, engineer, Process Development Section, GM Process Development Staff, before the A.S.L.E., Buffalo, New York, April 21; title: A Practical Look at Hydraulic Fire Resistant Fluids.

Reuben R. Jensen, master mechanic, Detroit Transmission Division, before the Division of Adult Education, Wayne State University, Detroit, April 29; title: Help in Meeting the Lubrication Requirements of Modern Machines and Methods.

Manufacturing

Leo J. Nartker, superintendent, Quality Control Department, Delco Products Division, before the Dayton, Ohio, section of the American Society for Quality Control, February 5; title: A Method of Determining Sampling Plans on a Basis of Minimum Overall Costs.

Claude M. Willis, safety supervisor, Delco Products Division, before the Safety Council, Dayton, Ohio, February 4; title: Industrial Safety, and before the safety class of the Cincinnati, Ohio, chapter of the Foreman's Club, March 10; title: Power Press Guarding.

Paton M. Zimmerman, senior production engineer, Fisher Body Division, before the Engineering Institute on Industrial Noise Control, Madison, Wisconsin, March 11; title: Noise Reduction at Fisher Body and Other GM Divisions.

Peter L. Fucinari, staff engineer, GM Process Development Staff, before the A.S.T.E., Detroit, March 12; title: How Are New Processing Techniques Affecting Tool Engineering.

H. M. Benson, chairman, Business and Accounting Department, General Motors Institute, before the Detroit section of the American Material Handling Society, March 17; title: New Material Handling Equipment Today for Profit Tomorrow.

John Schachinger, Jr., assistant chief engineer, Body Engineering Activity, Fisher Body Division, before the S.A.E. national production meeting, Detroit, March 20; title: How Can We Reduce Metal Finishing Costs?

Glenn E. Wanttaja, senior project engineer, GM Process Development Staff, before students of Wayne State University, Detroit, March 25; title: Applications of Computers and Servo-Mechanisms in Manufacturing Processes.

GM Process Development Staff engineers who made presentations at the S.A.E. national aeronautic meeting, New

York City, March 31-April 1, included: **Harry D. Hall**, director, Process Development Section, title: The Shop Man's Operations Research; **S. B. Sherwood**, supervisor, quality control committees, Production Engineering Section, title: What Does Reliability Concept Mean to the Manufacturing Man; and **Charles A. Nichols**, technical assistant to the vice president in charge of the Process Development Staff, panel discussion leader, topic: Looking Ahead Ten Years in Manufacturing.

David Milne, supervisor, materials and processes, Production Engineering Section, GM Process Development Staff, before the American Power Conference, Chicago, April 1; title: Water Conservation in General Motors.

John Q. Holmes, director, Production Engineering Section, GM Process Development Staff, before the Providence, Rhode Island, section of the A.S.M.E., April 4; title: Standards for Use in Manufacturing.

Robert B. Colten, staff engineer, GM Process Development Staff, before students of Purdue University, April 9; title: Development of an Effective Training Program for Numerical Control.

Robert D. McLandress, director, Work Standards and Methods Engineering Section, GM Process Development Staff, before the Top Management Seminar, Rock Island, Illinois, April 9; title: Industrial Management—Methods and Standards.

Kenneth Downing, engineer, GM Process Development Staff, before the Michigan Society of Professional Engineers, Detroit, April 21; title: Introduction to the Study of Development in Relation to Community Planning.

Roy P. Trowbridge, director, Engineering Standards, GM Engineering Staff, before the American Standards Association, Kansas City, Missouri, May 6; title: Lack of Participation in International Standardization a Threat to American Industry.

Carl F. Schaening, assistant in charge, Engineering Standards, GM Engineering Staff, before students of the University of Wisconsin, Madison, May 7; member of a panel discussing Fastener Standardization.

Frank H. Williams, staff engineer, GM Process Development Staff, before the A.S.T.E., Muskegon, Michigan, May 12; title: Process Development in Tool Engineering.

Robert M. Critchfield, vice president in charge of GM Process Development Staff, before the A.S.M.E., Detroit, May 13; title: Manufacturing Challenges.

D. F. Flanders, head, Administrative Services Department, Allison Division, before the 4th Annual Quality Control Symposium of the American Society for Quality Control, Dallas, Texas, March 14; title: Reliability Analysis Program, and before the A.S.M.E. National Production Engineering Conference, Detroit, May 13; title: Product Reliability Measurement.

Metallurgy

Harold A. Kahler, liaison engineer, Electrochemistry and Polymers Department, GM Research Laboratories, before the Montreal, Canada, chapter of the American Society for Metals, March 24; title: Control of Electroplating Operations.

R. F. Beck, staff engineer, Detroit Transmission Division, before the Malleable Founders Society, Cleveland, Ohio, April 8 and 9; title: Use of Malleable and Pearlitic Iron in Transmission Work.

S. R. Prance, chief metallurgist, Inland Manufacturing Division, before the Toledo, Ohio, chapter of the A.S.M., April 9; title: Selection and Heat Treatment of Tool Steels.

Manuel Ben, supervisor, Electrochemistry and Polymers Department, GM Research Laboratories, before the Buffalo, New York, chapter of the American Electroplaters Society, April 11; title: Hard Chromium Plating at General Motors Research Laboratories.

Fred J. Webbere, supervisor, Metallurgical Engineering Department, GM Research Laboratories, before the Muncie, Indiana, chapter of the A.S.M., May 12; title: Gray Iron as an Engineering Material.

Dean K. Hanink, chief metallurgist, Aircraft Engine Operations, Allison Division, before the Kokomo, Indiana, Engineering Society, February 23; and before the Western Metals Congress, Los Angeles, March 16; title: Some Problems Encountered and Solutions Developed on Materials Application to Turbojet and Turboprop Power Plants, and before the 15th Meeting of the Joint Army-Navy-Air Force Solid Propellent Group, symposium on fabrication and design—inert parts, Washington, D. C., June 17; title: The Development of a Metallurgical Laboratory Test Which Correlates With Pressure Vessel Behavior.

Miscellaneous

Martin J. Caserio, general manager, Delco Radio Division, before members of Phi Kappa Phi Honor Society, Michigan College of Mining and Technology, Houghton; title: Scholarship and Professional Development.

A. T. Bassett, Jr. experimental engineer, Frigidaire Division, before the Frigidaire Co-op Club, DeWitt Village, Ohio, February 16; title: Thermoelectric Cooling.

Joseph M. Biedenbach, head, Science Department, General Motors Institute, before Teen Age Civil Defense Clubs of Genesee County, Michigan, February 19; title: Radioactive Fall Out.

R. W. Oyler, assistant chief engineer, Guide Lamp Division, before the Alpha Eta field chapter of Phi Delta Kappa, Indianapolis, Indiana, March 11; title: Engineering Personnel Appraisal and Rating Program.

Tim Hoffman, program supervisor, Plant Management Training, General Motors Institute, before the Dayton, Ohio, chapter of the Comptrollers of America, March 12; title: Management Development in Business.

F. L. Mackin, chairman, Engineering Shop Department, General Motors Institute, before the Fluid Power Control Conference, Oklahoma State University, March 17; title: Fundamentals of Fluid Power Systems.

Bert T. Olson, plants manager, Delco Products Division, before the Foremen's Club of greater Cincinnati, Ohio, March 10; title: The Uncommon Man; before the junior chapter of the Society for Advancement of Management, Athens, Ohio, March 13; title: Individual Responsibility for Self Development; and at the Third Annual Management Conference, Columbus, Ohio, March 21; panel discussion: What the Boss Expects From the Foreman—What the Foreman Expects From the Boss.

Philip B. Zeigler, chief engineer, Saginaw Steering Gear Division, before Michigan College of Mining and Technology plant tour group, March 24; title: Engineering Developments.

Merton Jacobs, member, Technical Education Department, AC Spark Plug Division, Milwaukee plant, before the American Power Conference, Chicago,

March 31; title: Electronic Training Program—GM Institute, AC Spark Plug.

Charles Newman, senior instructor, Product Engineering Department, General Motors Institute, before the Engineering Society of Detroit, April 1; title: Non-Technical Reading for Engineers.

Charles A. Chayne, vice president in charge of Engineering Staff, before members of Tau Beta Pi Society, Warren, Michigan, January 10; title: Engineering in GM; before the National Association of Fleet Administrators, Detroit, March 5; title: A Frank Look at Highway Safety; and at Delaware's Fourth Annual Highway Day, Wilmington, April 6; title: Highway Safety.

Arthur P. Armington, supervisor, Sales Development Department, Euclid Division, before the Massachusetts Institute of Technology Faculty Club, Boston, April 7; title: Birth of an Off-Highway Hauler.

J. R. Doidge, chief engineer, Detroit Transmission Division, before a Ypsilanti, Michigan, Business-Industry-Education Group, April 14; title: Industry's Support of High School Science.

W. A. Bychinsky, chief engineer—automotive products, AC Spark Plug Division, before the Flint, Michigan, Insurance Women Association, March 25; title: Atoms, Electronics, and You, and before the World Congress of Flight, Las Vegas, April 17; title: Latest Advances in Aircraft Spark Plugs and Jet Igniters.

Herbert L. Karsch, project manager, Advance Weapons Systems Department, Allison Division, before the Indianapolis, Indiana, section of the Institute of Aeronautical Sciences, February 19; title: Early Foreign Rocket Development, and before the Fort Wayne, Indiana, section of the American Rocket Society, April 18; title: Far Side Rocket Research Program.

Wallace E. Wilson, general manager, Rochester Products Division, before administrators of the Rochester, New York, Industrial Management Council, April 21; title: Suggestions, Too, Are Everybody's Business.

Leo Marcus, structure design engineer, Allison Division, before the annual meeting of the American Society of Civil Engineers, Cleveland, Ohio, May 4; title: Numerical Analysis of Conical Shells Under Symmetrical Conditions for Calculation by Electronic Computers.

R. S. Braden, senior project engineer, Frigidaire Division, before the Mid-Eastern Electric Space Heating Council, Philadelphia, May 14; title: Analysis of the Heat Pump Problem.

Research

Albert C. Ottolini, research chemist, GM Research Laboratories, before the Detroit chapter of the Optical Society of America, February 23; title: Spectrographic Completion of Chemical Methods.

A. Sorensen, Jr., research engineer, AC Spark Plug Division, Milwaukee plant, before the 27th Shock and Vibration Symposium, February 25; title: A Critical Look at Vibration Fixture Performance.

Paul T. Vickers, supervisor, Engineering Development Department, GM Research Laboratories, before the A.S.M.E. Gas Turbine Power Conference, Cincinnati, Ohio, March 8; title: Rotary Regenerators for the Whirlfire Vehicular Turbines.

Douglas J. Harvey, senior research metallurgist, GM Research Laboratories, before a joint meeting of the Saginaw Valley, Michigan, chapter of the American Society for Metals and the American Welding Society, March 12; title: Research at the General Motors Technical Center.

Henry L. Garabedian, assistant head, Nuclear Power Engineering Department, GM Research Laboratories, before the American Mathematical Society's Symposium on the Mathematical Aspects of Nuclear Reactor Theory, New York City, April 23; title: Core Kinetics.

W. E. Hauth, Jr., staff scientist, AC Spark Plug Division, before the International Resistance Corporation Symposium, Philadelphia, April 27; title: Use of Ceramics in Electronics.

Technical Careers and Vocational Guidance

Don Everett and **Alex Kailing,** Gyro Engineering Department, AC Spark Plug Division, Milwaukee plant, before students of Hartland High School, February 19; title: Electrical Engineering.

Lavern M. Aurand, research metallurgist, AC Spark Plug Division, before science students of Whittier Junior High School, Flint, Michigan, February 19; title: Metallurgy.

Charles E. Fausel, manufacturing superintendent, Central Foundry Division, before students of the University of Illinois, February 27; title: Opportunities in the Foundry Industry.

F. E. Smith, senior staff assistant, Design and Drafting Department, Fisher Body Division, before students of Fraser, Michigan, High School, March 2; title: Position of Drafting in Industry.

Joseph J. Rosalik, design group leader, Cadillac Motor Car Division, before students of St. Alphonsus High School, Detroit, March 5; title: Drafting as a Career.

Norbert Sem, head, Test Fixture Design Department, AC Spark Plug Division, Milwaukee plant, before students of the Milwaukee School of Engineering, March 6; title: Test Fixture Engineering.

W. S. Phelps, general superintendent, production, Transmission and Locomotive Parts Operation, Allison Division, before Indianapolis, Indiana, industrial high school teachers, March 6; title: What Industry Looks for in the Production Worker and Supervisor.

Fred Jantz, group leader, design, Body Design Department, Oldsmobile Division, before the Illinois Vocational Association and Industrial Education Association, Peoria, March 20; title: Graphic Illustrations in Industry.

M. E. Otterbein, manager, research and development, Hyatt Bearings Division, before students of Chatham, New Jersey, High School, Engineers Committee for Student Guidance, March 25; title: Mechanical Engineering.

Arthur F. Underwood, manager, Research Laboratory, GM Research Laboratories, before the S.A.E. junior activity session, Detroit, April 6; title: Opportunities for the Engineer in Engineering.

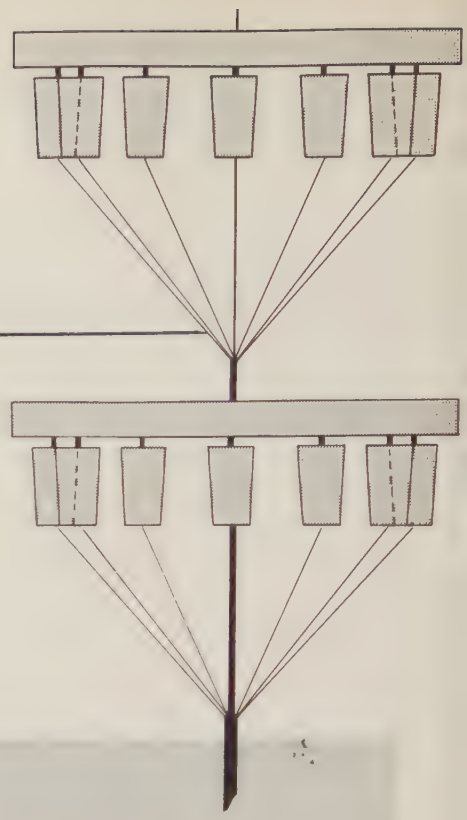
G. E. Smutny, drafting supervisor, Electro-Motive Division, before students of Proviso High School, Maywood, Illinois, April 14; title: Drafting—An Engineering Fundamental.

Carl M. Smith, drafting group supervisor, Chevrolet Motor Division, before students of Roseville, Michigan, High School, March 11; title: Drafting as a Vocation.

Carl M. Smith and **Harold R. Seymour,** assistant chief draftsman, Chevrolet Motor Division, before students of Utica, Michigan, High School, April 21; title: Drafting as a Vocation.

A Typical Problem in Engineering:

Calculate the Burst Strength of a Braided Rubber Hose from Design Characteristics



Designing a braided rubber hose to have sufficient burst strength involves calculations influenced by variables relating to such factors as the function of the hose, the materials being used, and the equipment used to fabricate the hose. Once a braided hose is fabricated, it is an easy matter to determine experimentally what the burst strength will be. Making a hose construction for such a purpose, however, is an expensive and time consuming project. It is frequently necessary, therefore, for engineers to calculate the burst strength of a hose from certain design characteristics dictated by job requirements.

THE design of a braided rubber hose is based on the critical examination of many variables peculiar to rubber hose products. In general, the variables a designer considers deal with the type of elastomer and reinforcing material to use, the service and safety requirements, and the lay of the reinforcing material.

Braided rubber hose is usually comprised of four main parts—the inner tube, the reinforcing material, the outer cover, and the liner material between the two layers of reinforcing material (Fig. 1). If only one layer of reinforcement is used, then the liner is eliminated.

The selection of an elastomer to use for the inner tube, liner, and outer cover is most critical from the standpoint of hose performance. The nature of the fluid the hose will carry governs the selection of the elastomer for the inner tube. The elastomer for the outer cover is selected to provide maximum protective properties for the reinforcing material.

When examining the service requirements for a hose, the designer considers such factors as working pressure, bursting requirements, and continuous or intermittent service conditions—for example, high or low temperatures. Sometimes, a specific requirement like high or low expansion under pressure becomes the point around which the hose is designed.

Safety requirements represent a critical design point. Safety factors up to 10 are common for such automotive applications as hydraulic brake hose. Even though normal braking pressures do not exceed 600 psi in such an application, the burst strength is usually around 6,000 psi or higher.

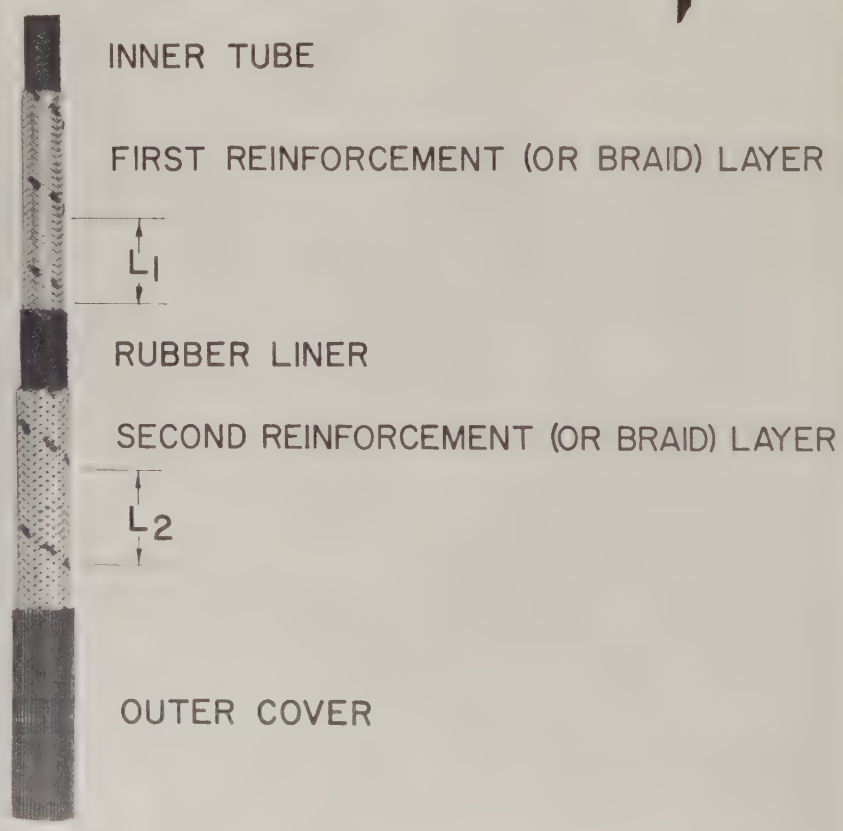


Fig. 1—Braided hose is usually comprised of an inner tube, one or more reinforcing layers, and an outer cover. A rubber liner is used between the layers of reinforcing material. The liner is eliminated if the hose has only one layer of reinforcing material. Dimensions L_1 and L_2 represent the lead of the braid pattern used for the first and second reinforcement layers.

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A somewhat unusual application for force analysis fundamentals

In many cases the selection of the reinforcing material accounts for the success or failure of a hose design. Some of the most important properties of a reinforcing material are the degree of flexibility, heat resistance, and water resistance.

In general, textile fibers are more flexible than metallic yarns and are preferred when a high degree of flexibility is desired. For heat resistance, metallic yarns are superior to textile fibers. However, textile fibers may be used when temperature requirements are not extremely high.

For water resistance, cotton and metallic yarns are superior to the remaining textile fibers. Recent work, however, has indicated that several other yarns can be used satisfactorily for water resistance applications.

One more factor to consider is the design of the reinforcing material—that is, the way the yarns or cords should lie on the hose in order to give maximum efficiency to the finished product. In braided hose, the lay of the reinforcing material determines the characteristics that the hose will have under pressure and its ultimate burst strength.

Braided hose is manufactured on equipment referred to as a *braider* (Fig. 2). Depending on the type of braider used, various types of patterns can be obtained with the reinforcing material. The most commonly used braid pattern is the 2/2 pattern (two over two pattern, Fig. 3).

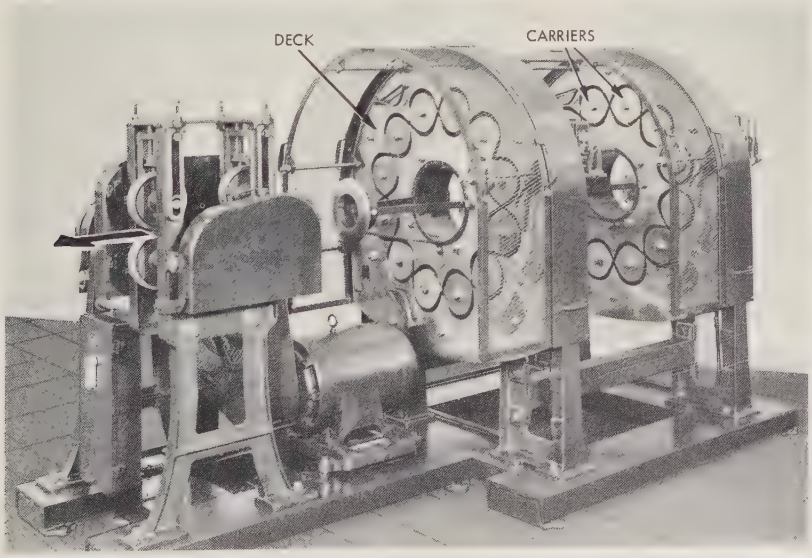
The braider is a device in which the yarns come off the respective bobbins, or spools, as they move in and out of the frame, thereby permitting interwinding of the yarns[1]. The yarns pass over one another in such a manner that each yarn winds a sinuous course through the ribbon-like texture produced. This ribbon-like texture is called *braid*. There are various types of braid, such as flat, tubular round, and fancy. Tubular round braid is used in the manufacture of braided hose. To make tubular braid, two endless interwinding tracks are used (Fig. 4).

In any braider, a bobbin is placed on a metallic carrier which rides along a slot in a steel plate. The carrier grips the plate by means of flanges on the carrier feet. The carriers are moved by horn gears. The path of the carrier determines the type of braid to be made. The design of the horn gear determines the braid pattern.

The components of a braid which interlace independently are called *strands*. A strand is formed by one or more yarns running together. A strand, therefore, refers to the total number of independent yarns coming off one bobbin during braiding. When one, two, three, or more yarns come off a bobbin simultaneously, the bobbin is said to have one, two, three, or more *ends*.

The most important single factor affecting the behavior of a braided hose under pressure is the *braid angle* (Fig. 3—left), which is the angle the yarns of the reinforcing material makes with the longitudinal axis of the hose. The *angle of equilibrium*, or *neutral angle*, is the braid angle that permits neither expansion nor contraction under pressure, assuming that the reinforcing material has no stretch and that there is no appreciable wall thickness.

In a hose braid, a constant number of picks (Fig. 3—right) is required for a strand to leave a given point and return to an exactly equivalent position further along the braid. The number of picks per inch between the two equivalent positions of any strand is a quantity numerically equal to half the total number of strands or to half the number of carriers, (since one strand is withdrawn from the one bobbin placed on each carrier).



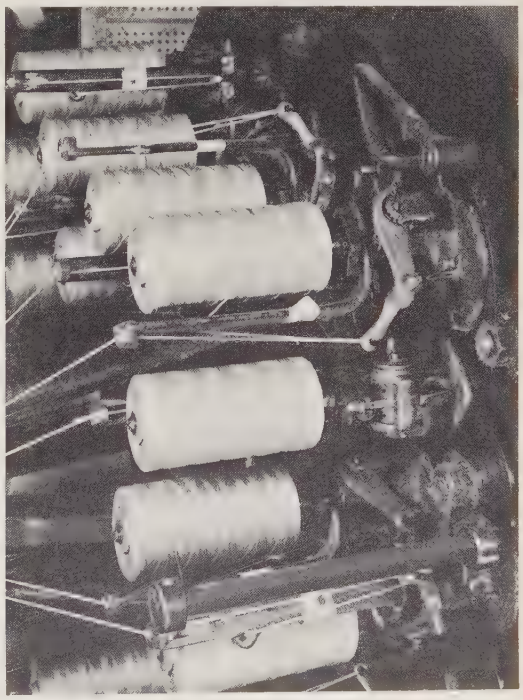


Fig. 2—Shown at the left is a typical horizontal, rubber hose braider. This particular braider has two decks, each comprised of an equal number of carriers. A braided hose is made by passing the inner tubing of the hose through the braider (in the direction indicated by the arrow). As the inner tubing moves through the braider, reinforcement layers are applied. Material for the reinforcement layers is fed from bobbins mounted on the carriers, as shown at the right.

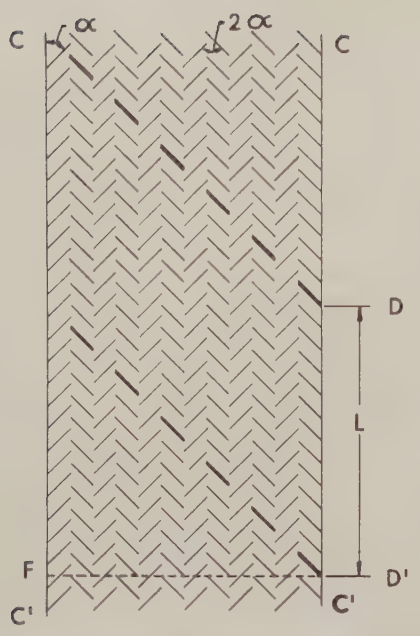
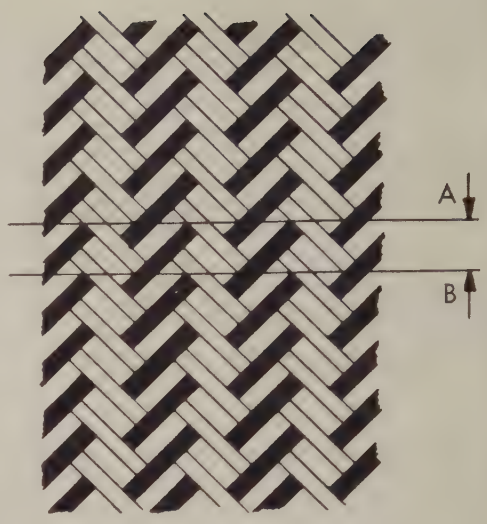


Fig. 3—The most commonly used braid pattern is the 2/2 pattern (two over two pattern), shown here at the left in a view which has the pattern cut along the longitudinal axis *C-C'* and opened outward. In this pattern each strand goes over the two neighboring strands, then under two strands, then over two strands, and so on. This effect is obtained by using horn gears, each having four horns, or notches. The distance *L* between two equivalent positions *D* and *D'* of a strand is called the *lead* of the braid pattern. The periphery of the pattern is represented by *F-D'*. The angle α is the *braid angle*. This is the angle the yarns of the reinforcing material make with the longitudinal axis *C-C'* of the hose. One repeat of a braid weave measured along the braid axis (right) is called a *pick*. The distance *A-B* represents one pick.



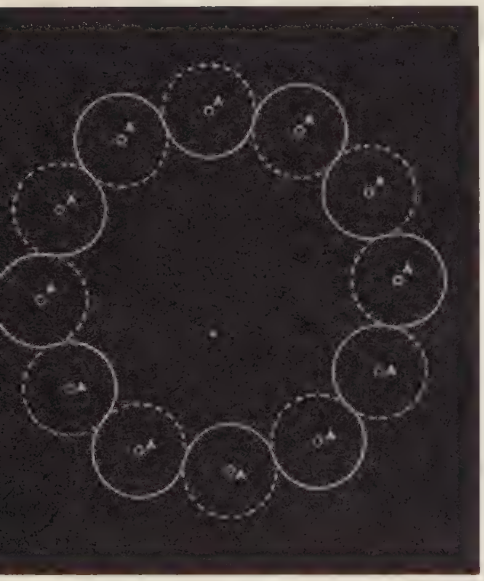


Fig. 4—To make a tubular round braid, two endless interwinding tracks are used. The braid is made at the center of the circle formed by the mean position of the paths of the carriers (point *A*). This point is called the *braiding point*. One set of carriers controlling half of the strands follows the full line, while the other set of carriers controlling the remaining strands moves in the opposite direction along the dotted line.

The braiders used to manufacture braided hose have one, two, or three decks, with each deck having an equal number of carriers. The number of reinforcing layers desired determines the number of decks to use. Each deck has 24, 36, or 48 carriers depending mainly on the size of the hose to be made and the area to be covered by the braids. A braided hose is made by passing the inner tubing through the braider. The inner tubing may or may not be supported by a mandrel. The reinforcement, therefore, lays on the tubing at the braiding point and forms a reinforced structure.

Problem

The problem is to calculate the burst strength of a braided hydraulic brake hose having two layers of reinforcing material. The following design characteristics are to be used:

First Reinforcement Layer

- Tensile strength of the yarn = T_{E1} = 21.0 lb
- Number of yarns forming one strand = E_1 = 1
- Braid diameter (before pressure is applied) = d_1 = 0.290 in.
- Picks per inch = P_1 = 20.5.

Second Reinforcement Layer

- Tensile strength of the yarn = T_{E2} = 14 lb
- Number of yarns forming one strand = E_2 = 2
- Braid diameter (before pressure is applied) = d_2 = 0.395 in.
- Picks per inch = P_2 = 13.

To manufacture the hose, a braider having two decks of 24 carriers each will be used.

To solve the problem will require the development of two equivalent equations each giving the burst strength of a braided hose at the angle of equilibrium α. These two equations may then be used to calculate the burst strength. The braided hose can be treated as the center section of a thin-walled vessel supported by the yarn of the reinforcing material which spirals about its longitudinal axis.

There are three points which must be taken into account: (a) the yarn should be considered as having no stretch, (b) the thickness of the thin-walled vessel, and also the thickness of the braid, is to be considered negligible when compared to the inside diameter of the vessel, and (c) the ultimate burst strength of the braided hose will be the sum of the burst strength for each of the two layers of reinforcing material, calculated separately.

The solution to the problem will appear in the October-November-December 1959 issue of the General Motors Engineering Journal.

Bibliography

1. Brunnschweiter, D., "Braids + Braiding," *Journal of the Textile Institute*, Vol. 44, No. 9 (September 1953), pp. 666-86.

Other related information in this field includes the following:

Marin, Joseph, *Strength of Materials* (New York: The MacMillan Company, 1949), pp. 28-30.

Solution to the Previous Problem:

Improve Projection-Weld Quality Through Statistical Methods*

By GORDON L. WEBSTER
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Statistics provides an effective way to interpret variation

The establishment of a program leading to a measurable method for evaluating projection weld quality and recommendations for improving weld quality required first a gathering of data dealing with three variables affecting weld quality: tensile strength of the weld, projection height, and zinc-plate thickness. It was then required to apply statistical methods of analysis to the data gathered for each variable. This is the solution to the problem presented in the April-May-June issue of the GENERAL MOTORS ENGINEERING JOURNAL. The overall approach used is to apply average and range charts and frequency histogram techniques to provide information about weld strength and the factors affecting it, as well as to suggest further areas for investigation.

THE data for the weld strength and projection height variables were in the form of sample measurements taken over a period of time. These two variables, therefore, will be analyzed through the use of the average range to determine machine capability. The zinc-plate thickness variable will be analyzed through computations from the frequency distribution, in which form the data were obtained.

Weld-Strength Analysis

Since impact tests and visual inspection methods would not provide measurable results of projection weld strength, it was decided to evaluate weld strength in a way which would give numerical values. Such a procedure would provide an indication of the tensile strength of individual welded parts as well as some measure of control over machine output. The range of tensile strengths within a sample would be indicative of the ability of the machine to weld consistently. The change occurring in the average tensile strength between samples would provide information with respect to the tendency for the welding machine to drift over a period of time.

The first step in the weld-strength analysis is to establish the sample averages and ranges (Table I). The average range $\bar{R}$ for the weld strength samples is then calculated as the sum of the ranges divided by the number of samples. The average range is calculated as follows:

$$\bar{R} = \frac{\Sigma R}{N} \qquad (1)$$

where

$\bar{R}$ = average range

ΣR = sum of the ranges

N = number of samples

$$\bar{R} = \frac{9{,}275}{53} = 175 \text{ lb.}$$

Next, the upper and lower limits of variation are calculated as follows, based on a sample size of two[1].

$$UCL_R = D_4\bar{R} \qquad (2)$$

where

UCL_R = upper control limit for ranges

D_4 = computation factor for the upper control limits on a chart for ranges

$\bar{R}$ = average range

$$UCL_R = (3.27)(175) = 572 \text{ lb.}$$

$$LCL_R = D_3\bar{R} \qquad (3)$$

LCL_R = lower control limit for ranges

D_3 = computation factor for the lower control limit on a chart for ranges

$\bar{R}$ = average range

$$LCL_R = (0)(175) = 0 \text{ lb.}$$

Referring to the tabulated values for ranges (Table I) shows that the range of 950 lb for Sample No. 28 lies beyond the upper control limit of 572 lb. This indicates that there was some assignable reason for this non-random value. This particular range, therefore, is deleted from the total, and a new average range is computed for the remaining 52 samples as follows:

$$\bar{R}' = \frac{\Sigma R}{N'}$$

where

$\bar{R}'$ = modified average range

N' = modified number of samples

$$\bar{R}' = \frac{8{,}325}{52} = 160 \text{ lb.}$$

New control limits also must be established, as follows:

$$UCL_R = (3.27)(160) = 523 \text{ lb}$$

$$LCL_R = (0)(160) = 0 \text{ lb.}$$

The new control limits show that all 52 ranges lie within limits, thereby indicating a stable pattern of variation.

To determine the capability of the welding machine to produce parts of consistent tensile strength, the universe standard deviation σ'_X must be estimated from the average range as follows, taking into account the factor for computing the standard deviation from the average range[2]:

$$\sigma'_X = \frac{\bar{R}'}{d_2} \qquad (4)$$

where

σ'_X = universe standard deviation

$\bar{R}'$ = modified average range

d_2 = computation factor used to determine the spread of individual measurements

$$\sigma'_X = \frac{160}{1.128} = 142 \text{ lb.}$$

The standard deviation is then multiplied by six to establish the range of variations which will occur 99.73 per cent of the time through chance causes.

$$6\sigma'_X = (6)(142) = 852 \text{ lb.}$$

*This is the solution to a representative problem based on data taken from a General Motors Institute Fifth Year Project Study Report entitled "The Application of Statistical Quality Control to Resistance Welding Operations," prepared by Victor Abla while he was a G.M.I. co-op student sponsored by Ternstedt Division. Mr. Webster served as Institute Supervisor during preparation of the Report.

Sample No.	Each Item in Sample X_1	Each Item in Sample X_2	Total	Average for Sample	Range for Sample
1	1925	2000	3925	1963	75
2	1950	2000	3950	1975	50
3	1850	1950	3800	1900	100
4	1800	1950	3750	1875	150
5	1850	1900	3750	1875	50
6	2000	2000	4000	2000	0
7	2100	2000	4100	2050	100
8	1750	1800	3550	1775	50
9	1975	1975	3950	1975	0
10	1550	1950	3500	1750	400
11	2000	1600	3600	1800	400
12	1900	1800	3700	1850	100
13	1850	2100	3950	1975	250
14	1750	1850	3600	1800	100
15	1500	1450	2950	1475	50
16	1675	1650	3325	1663	25
17	1650	1475	3125	1563	175
18	1850	1825	3675	1838	25
19	1700	1525	3225	1613	175
20	1725	1500	3225	1613	225
21	1300	1100	2400	1200	200
22*	1350	1450	2800	1400	100
23	1750	1800	3550	1775	50
24	1700	1800	3500	1750	100
25	1625	1775	3400	1700	150
26	1500	1875	3375	1688	375
27	1575	1725	3300	1650	150
28	1850	900	2750	1375	950
29	1750	1600	3350	1675	150
30	1900	1950	3850	1925	50
31	1525	1525	3050	1525	0
32	1800	1900	3700	1850	100
33	1800	1650	3450	1725	150
34	1600	1800	3400	1700	200
35	1300	1700	3000	1500	400
36	1775	1625	3400	1700	150
37	1350	1800	3150	1575	450
38	1650	1700	3350	1675	50
39	1900	1825	3725	1863	75
40	1850	1700	3550	1775	150
41	1700	1825	3525	1763	125
42	1525	1750	3275	1638	225
43	1700	1350	3050	1525	350
44	1800	1400	3200	1600	400
45	1475	1150	2625	1313	325
46	1900	1800	3700	1850	100
47	1500	1850	3350	1675	350
48	1600	1825	3425	1713	225
49	1600	1825	3425	1713	225
50	1800	1675	3475	1738	125
51	1625	1900	3525	1763	275
52	1625	1650	3275	1638	25
53	1700	1725	3425	1713	25
		TOTALS		90,996	9,275

*Changed Electrodes.

Table I—To investigate the tensile strength of the projection welds, 53 samples were taken with each sample consisting of two specimens. From the measurements made, sample averages and ranges were then tabulated, as shown here. The tensile strengths for each specimen are tabulated in columns X_1 and X_2. The individual tensile strength measurements for each sample are added and the sum is listed in the *TOTAL* column. This sum is then divided by the number of measurements in each sample and is listed in the *AVERAGE* column. The difference between the high and low measurements in each sample is determined by subtracting the lower measurement from the higher measurement. This value is listed in the *RANGE* column. The averages and ranges are summed and the total listed at the end of each column.

This last calculation indicates that the welding machine will produce welds having a tensile strength variation of 852 lb.

The average value of weld strength is computed by dividing the sum of the sample averages (deleting the reading for Sample No. 28) by the number of samples.

$$\bar{\bar{X}}' = \frac{\Sigma \bar{X}}{N'} \qquad (5)$$

where

$\bar{\bar{X}}'$ = modified average of sample averages

$\Sigma \bar{X}$ = sum of sample averages

N' = modified number of samples

$$\bar{\bar{X}}' = \frac{89{,}621}{52} = 1{,}723 \text{ lb.}$$

The upper and lower control limits of variation for averages of samples of two is then established as follows:

$$UCL_{\bar{X}} = \bar{\bar{X}} + A_2\bar{R}' \qquad (6)$$

where

$UCL_{\bar{X}}$ = upper control limit for averages

$\bar{\bar{X}}'$ = modified average of sample averages

A_2 = computation factor[1] for control limits on an $\bar{X}$ chart for averages

$$UCL_{\bar{X}} = 1{,}723 + (1.88)(160) = 2{,}024 \text{ lb.}$$

$$LCL_{\bar{X}} = \bar{\bar{X}}' - A_2R' \qquad (7)$$

where

$LCL_{\bar{X}}$ = lower control limit for averages

$$LCL_{\bar{X}} = 1{,}723 - (1.88)(160) = 1{,}422 \text{ lb.}$$

It will be noted that the difference between the upper and lower control limits is 2,024 − 1,422 or 602 lb, whereas the six standard deviations provided a variation of 852 lb. The resulting difference between 852 lb and 602 lb is a true difference, since sample averages show less variation than the variation of individual measurements.

A summary of the weld strength analysis data shows that the average strength of the welds produced during the study is 1,723 lb (Fig. 1). Also, the welding machine can be expected to produce welds having strength variations of 852 lb, or between 2,149 lb and 1,247 lb which is the average plus and minus three standard deviations. A reduction of the overall strength variation will necessitate further study of the variables affecting the process. The information gathered so far, however, allows the establishment of a realistic specification for weld tensile strength.

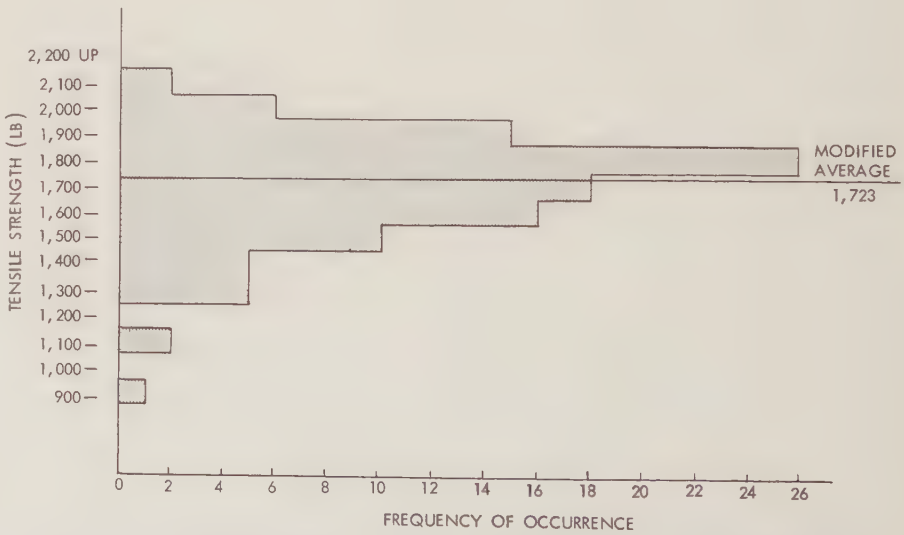


Fig. 1—The average tensile strength of the welds produced is 1,723 lb. This histogram also shows that the projection welding machine produced welded parts having tensile strengths varying between 900 lb and 2,100 lb.

Sample No.	Each Item in Sample				Total	Average for Sample	Range for Sample
	X_1	X_2	X_3	X_4			
1	.028	.030	.029	.030	.117	.0292	.002
2	.027	.029	.027	.029	.112	.0280	.002
3	.028	.029	.027	.030	.114	.0285	.003
4	.028	.028	.029	.027	.112	.0280	.002
5	.029	.030	.029	.030	.118	.0295	.001
6	.029	.030	.029	.027	.115	.0287	.003
7	.029	.031	.029	.030	.119	.0297	.002
8	.028	.029	.028	.030	.115	.0287	.002
9	.029	.030	.028	.030	.117	.0292	.002
10	.030	.031	.029	.030	.120	.0300	.002
11	.030	.029	.030	.031	.120	.0300	.002
12	.029	.031	.028	.029	.117	.0292	.003
13	.028	.030	.029	.031	.118	.0295	.003
14	.028	.030	.028	.030	.116	.0290	.002
15	.028	.030	.029	.030	.117	.0292	.002
16	.029	.030	.029	.030	.118	.0295	.001
17	.029	.031	.029	.030	.119	.0297	.002
18	.029	.030	.029	.030	.118	.0295	.001
19	.030	.031	.029	.030	.120	.0300	.002
20	.029	.030	.029	.030	.118	.0295	.001
21	.029	.031	.030	.031	.121	.0303	.002
22	.031	.031	.029	.030	.121	.0303	.002
23	.030	.031	.029	.030	.120	.0300	.002
24	.028	.029	.031	.030	.118	.0295	.003
25	.027	.029	.028	.027	.111	.0278	.002
26	.030	.028	.029	.029	.116	.0290	.002
27	.030	.029	.031	.029	.119	.0297	.002
28	.030	.029	.030	.031	.120	.0300	.002
29	.030	.028	.030	.029	.117	.0292	.002
30	.030	.029	.030	.029	.118	.0295	.001
31	.030	.029	.030	.029	.118	.0295	.002
32	.031	.028	.030	.028	.117	.0292	.003
33	.030	.029	.030	.029	.118	.0295	.001
34	.029	.029	.031	.029	.118	.0295	.002
35	.030	.029	.030	.030	.119	.0297	.001
36	.030	.030	.029	.028	.117	.0292	.002
37	.026	.027	.027	.028	.108	.0270	.002
38	.027	.027	.026	.028	.108	.0270	.002
39	.027	.026	.027	.028	.108	.0270	.002
40	.026	.026	.025	.026	.103	.0258	.001
41	.026	.027	.027	.027	.107	.0268	.001
42	.026	.027	.026	.027	.106	.0265	.001
43	.026	.027	.025	.026	.104	.0260	.002
44	.026	.027	.027	.028	.108	.0270	.002
45	.025	.026	.026	.027	.104	.0260	.002
46	.025	.026	.026	.026	.103	.0258	.001
47	.026	.027	.026	.027	.106	.0265	.001
48*	.035	.037	.035	.036	.143	.0358	.002
49	.034	.036	.035	.035	.140	.0350	.002
50	.035	.036	.035	.036	.142	.0355	.001
51	.036	.035	.034	.036	.141	.0353	.002
52	.035	.036	.035	.036	.142	.0355	.001
53	.035	.036	.035	.036	.142	.0355	.001
					TOTALS	1.5605	.097

*Changed Punch.

Table II—Tabulated in columns X_1 through X_4 are projection height measurements (in inches) for each specimen in the 53 samples. The tabulated information for the remaining columns is obtained in a manner similar to that used for Table I.

Observation of the chart of sample averages (Fig. 3 in the problem statement) shows a downward trend in weld strength over a period of time as a result of electrode wear. A further study would be necessary to extend the tool life and reduce the frequency of changing electrodes. The use of a control chart at the projection welding machine, however, should be recommended as an aid in indicating just when electrodes should be changed. The control limits for averages and ranges which have been calculated could then be used on the control chart as a means of maintaining the weld strength within the established practical limits of variation. Any points falling outside of the limits would be indicative of a change in the welding process resulting from some assignable cause which should be investigated.

It may be concluded that destructive tensile testing of samples is superior to inspection by either impact tests or by visual inspection of welds. Destructive testing allows weld strength to be expressed in measurable terms and specific information can be acquired to permit closer control over the process as the parts are being produced, as well as to indicate potential areas for quality improvement. The success of the destructive testing method, therefore, leads to a further recommendation that investigation be made as to the use of a special test fixture to test tensile strength of production welds instead of using flat test specimens.

Projection-Height Analysis

Since one of the factors affecting weld quality was the height of the welding projections, it was desirable to determine how well these heights, as produced, were meeting specifications and how capable the machine was of meeting specifications.

The range of projection heights within a sample indicates the ability of the machine to emboss projections of consistent height. The change occurring in the average height between samples provides information with respect to tool adjustment and wear over a period of time.

The first step in an analysis of projection height is to establish the sample averages and ranges (Table II). The average range R for the projection height samples is calculated by applying equation (1) and is found to be 0.0018 in.

The upper and lower control limits of variation for a sample size of four[2] are then computed by applying equations (2) and (3). The upper control limit is equal to 0.0041 in. and the lower control limit equals 0 in.

Since all sample ranges lie within the control limits, a stable pattern of variation exists. The capability of the machine to emboss projections of consistent height is determined by estimating the universe standard deviation. By applying equation (4), this deviation is calculated to be 0.00087 in. Six times the standard deviation gives 0.0052 in. as the range of

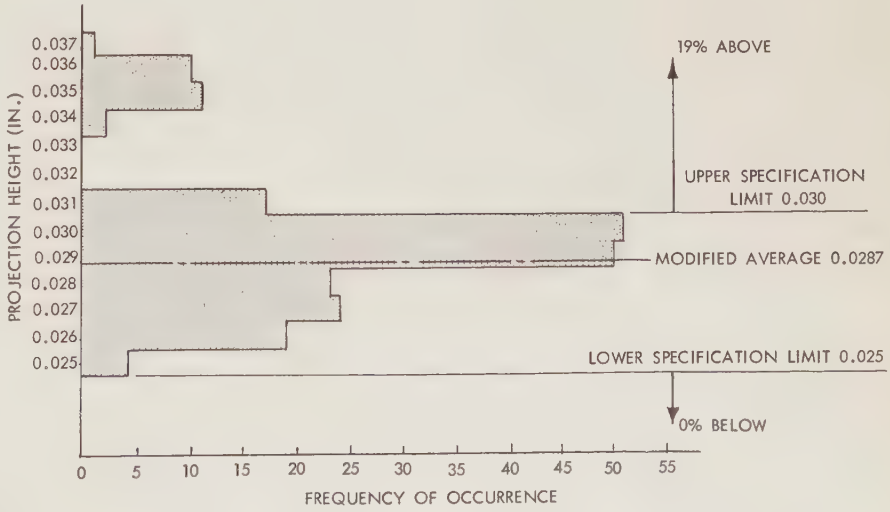


Fig. 2—The frequency histogram shown here for projection heights indicates that no parts were produced below the lower specification projection-height limit of 0.025 in. and that 19 per cent of the parts were produced above the upper specification limit.

variation which will occur 99.73 per cent of the time through chance causes.

Unlike the weld strength analysis, where there were no established specifications, it is not desirable to use the average value of projection height. Since the specification for limits of projection height are 0.025 in. to 0.030 in., it is more practical to use the specification mean of 0.0275 in. as a standard value for establishing the limits of variation. The upper and lower control limits of variation for averages of samples of four may be calculated by applying equations (6) and (7). The upper control limit equals 0.0288 in. and the lower control limit equals 0.0262 in.

As in the weld strength analysis, it will be noted that the difference between the upper and lower control limits for projection height is 0.0288 − 0.0262, or 0.0026 in., whereas the six standard deviations give a variation of 0.0052 in. Again, this is a true difference, since the averages of samples of four will vary just half as much as the individual measurements.

The calculations so far indicate that the machine is not capable of embossing all projections within specifications, even if held on the specification mean. That is, the machine capability of 0.0052-in. variation is greater than the maximum permitted variation of 0.005 in.

Cell	f	d	fd	fd^2
.00019	3	4	12	48
.00018	12	3	36	108
.00017	14	2	28	56
.00016	21	1	21	21
.00015	18	0	0	0
.00014	15	-1	-15	15
.00013	13	-2	-26	52
.00012	17	-3	-51	153
.00011	8	-4	-32	128
.00010	2	-5	-10	50
Totals	123		-37	631
	n		Σfd	Σfd^2

Table III—The information tabulated here is used to calculate the average zinc-plate thickness and the standard deviation for the zinc-plate thickness from the frequency distribution. The column headed *f* lists the frequency of occurrence of each thickness measured in the sample. The column headed *d* lists the deviation of the measurement from the assumed mean of 0.00015 in. In the *d* column, a zero value is shown opposite the measurement assumed as the mean and the cells are numbered positively and negatively in unit increments from this value. The *fd* and fd^2 columns represent product values of columns *f* and *d*.

It is possible by statistical methods, based on the normal curve of error, to estimate the percentage of parts out-of-specification even when the machine is held to the mean during production[3]. This percentage may be calculated using the following relationship:

$$Z = \frac{X_i - \bar{X}'}{\sigma'_X} \qquad (8)$$

where

Z = standard normal variate

X_i = lower specification limit

$\bar{X}'$ = specification mean

σ'_X = universe standard deviation.

Substituting:

$$Z = \frac{0.025 - 0.0275}{0.00087} = -2.87.$$

Using both the −2.87 value for Z and Table A of reference 3 provides the following information:

Per cent below = 0.21 per cent

Per cent above = 0.21 per cent (normal curve symmetrical about the mean).

The minimum out-of-specification production, therefore, would be 0.42 per cent of the parts run.

A study of the average and range chart for projection height (Fig. 4 in the problem statement) shows that the heights are being maintained near the upper specification limit the majority of the time. Applying equation (5) gives the average projection height produced as 0.0287 in. In the calculation for the average projection height, the last six samples were excluded. These samples were run after the change of the embossing punch and were obviously the result of incorrect adjustment.

A frequency histogram of projection height (Fig. 2) shows that none of the parts produced during the study had a projection height below the lower specification limit and that 19 per cent (41 of 212) of the parts produced had projection heights above the upper specification limit. The 19 per cent above value, however, is biased as a result of the last six samples. By applying statistical methods and equation (8) it is possible to estimate the percentage of parts which will be produced out-of-specification, based upon the process average of 0.0287 in. and excluding the obviously abnormal six samples. From equation (8), the normal variate Z is found to be −4.25. Using the −4.25 value for Z and referring to Table A of reference 3 shows that the Z value is beyond the range of the Table, indicating that the percentage of parts below the lower specification limit is zero per cent. To estimate the percentage above:

$$Z = \frac{X_i - \bar{\bar{X}}'}{\sigma'_X}$$

where

X_i = upper specification limit

$\bar{\bar{X}}'$ = modified process average

$$Z = \frac{0.030 - 0.0287}{0.00087} = 1.50.$$

Using this value for Z and referring to Table A of reference 3 shows that the percentage of parts above the upper specification limit would be 6.68 per cent.

A summary of the projection height analysis data obtained so far shows that the average height during the study is 0.0287 in. Also, the projection height can be expected to vary 0.0052 in., or between 0.0313 in. and 0.0261 in. which is the average plus and minus three standard deviations. It can be concluded, therefore, that under present conditions the machine for embossing projection heights is not capable of holding the specification range of 0.005 in. At the same process level, and barring maladjustment of the tools, it is estimated that 6.68 per cent of the parts produced would be above the upper specification. If the process level is shifted to and held at the specification mean of 0.0275 in. the minimum out-of-specification parts produced would be 0.42 per cent. A reduction of the overall variation would necessitate a further study of the variables affecting the projection height embossing process.

The use of a control chart at the machine should be recommended to make it possible to maintain the process level at or near the specification mean and also obviate the production of out-of-specification parts whenever the tooling is adjusted or changed. The use of a control chart would lessen considerably the possibility of producing parts beyond specification. The control limits for averages and ranges as computed in the preceding calculations may be used on the control chart to maintain the height within the established statistical limits of variation. Any points falling outside of

the limits indicate some change in the process which should be investigated.

In summary, statistical methods provide definite knowledge about projection height which may be used to improve product quality. Further statistical analysis should be applied to determine the relationship between projection height and weld strength.

Zinc-Plate Thickness Analysis

It is essential that parts concealed within the car body be zinc-plated to provide corrosion resistance. It is necessary, however, to burn off the zinc plating before fusion of parent metal is possible. The plate thickness, therefore, has a definite bearing upon weld quality. Analysis of the plate thickness frequency distribution provides knowledge about the average thickness and the variability of the thickness.

The first step in the zinc-plate thickness analysis is to calculate the average plate thickness, based on the data provided by the 123 samples used and the frequency of occurrence of each of the thicknesses measured (Table III).

The specification for thickness was 0.00011 in. minimum. The average plate thickness, therefore, can be calculated from the following relationship:

$$\bar{X} = X_o - \left(\frac{\Sigma fd}{n}\right)(c)$$

where

$\bar{X}$ = average zinc-plate thickness

X_o = assumed mean of 0.00015 in.

Σfd = summation value (Table III)

n = number of measurements

c = cell interval.

Substituting:

$$\bar{X} = 0.00015 + \left(\frac{-37}{123}\right)(0.00001)$$

$$\bar{X} = 0.000147 \text{ in.}$$

The standard deviation is calculated as follows:

$$\sigma_X = (c)\sqrt{\frac{\Sigma fd^2}{n} - \left(\frac{\Sigma fd}{n}\right)^2}$$

where

σ_X = sample standard deviation

c = cell interval

Σfd^2 = summation value (Table III)

n = number of measurements

Σfd = summation value (Table III).

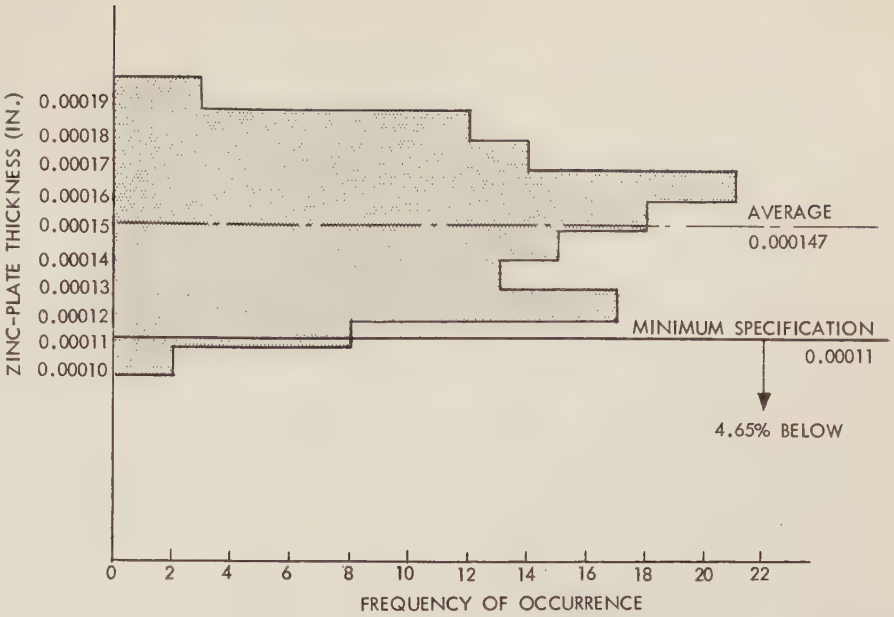


Fig. 3—The minimum specification for zinc-plate thickness was 0.00011 in. The average plate thickness for 123 samples was 0.000147 in. An analysis of the data showed that 95.35 per cent of parts were above the minimum specification.

Substituting:

$$\sigma_X = (0.00001)\sqrt{\frac{631}{123} - \left(\frac{-37}{123}\right)^2}$$

$$\sigma_X = 0.000022 \text{ in.}$$

Six times this standard deviation gives 0.000132 in. as the range of variation which will occur 99.73 per cent of the time through chance causes.

The limits of variation—that is, the average plus and minus three standard deviations—are 0.000213 in. and 0.000081 in. A comparison of these limits with the average plate thickness $\bar{X}$ of 0.000147 in. and six standard deviations of 0.000132 in. shows that all measurements are within limits and that a stable pattern of variation exists.

The upper and lower control limits for individuals are calculated as follows:

$$UCL_X = \bar{X} - 3\sigma_X = 0.000213 \text{ in.}$$

$$LCL_X = \bar{X} - 3\sigma_X = 0.000081 \text{ in.}$$

The normal variate for parts below the minimum specification is calculated from equation (8) to be −0.168. Using the value of −0.168 for Z and referring to Table A of reference 3 gives the percentage of parts below the minimum specification as 4.65 per cent.

An analysis of the zinc-plate thickness data shows, therefore, that the average plating thickness for the 123-piece sample is 0.000147 in. Although this thickness is well above the minimum specification of 0.00011 in. (Fig. 3), the average minus three standard deviations gives a lower limit of variation of 0.000081 in. which is below the specification.

It can be reasoned that a reduction in the average plate thickness would likely result in increased weld strength with a consequent detrimental effect on corrosion resistance. Even a reduction in average thickness with a concurrent reduction in the overall variation in order to assure all parts with thickness above the minimum would have an adverse effect on corrosion resistance. The dilemma thus posed is that an increase in weld strength quality can be effected only at the expense of a reduction in corrosion-resistance quality.

Fortunately, however, the technique of multiple correlation permits the evaluation of the overall concurrent effect of several independent variables upon a dependent variable. This suggests, therefore, that further statistical analysis can be made to determine the relationship between the combined factors of projection height and plate thickness upon the factor of weld strength.

Bibliography

1, 2, 3 Grant, E. L., *Statistical Quality Control* (New York: McGraw-Hill Book Co., Inc., 1952), pp. 513 (Table C); 512 (Table B); and 510 (Table A), respectively.

GM Engineers Develop Experimental Highway-to-Car Communications System

An experimental low-frequency communications system, designed to transmit voice messages from roadside transmitters to moving vehicles, was recently demonstrated before state and government highway, turnpike, traffic, and safety officials at the GM Technical Center. Originated by the GM Research Laboratories and developed in cooperation with Delco Radio Division, the highway communications system, called *Hy-Com*, is intended primarily as a driver aid and suggests a new medium for future highway safety and traffic control. Tests have indicated that a brief vocal message is likely to be more informative and cause drivers to react more quickly than any warning lights or buzzers actuated by radio signals from the roadside.

The idea of transmitting road-to-car voice messages is not new. The design of the GM Hy-Com system is different from other designs, however, in that the system uses *controlled* low frequency transmission to transmit messages only to cars in a specific highway area moving in the proper direction. Transistors are used throughout to provide reliability of operation over many years. In addition, the system is flexible and can be altered to fit the needs of highway engineers for possible installation along turnpikes and expressways.

Hy-Com Has Two Basic Parts

The Hy-Com communications system has two basic parts: (a) low frequency transmitters spaced along the roadside and (b) a transistorized receiver in the car. The transmitters can be used with either above-ground antennas or radiating loops buried along the roadside (Fig. 1).

Hy-Com is an electro-magnetic induction system designed to operate in the 10 to 20 kilocycle range, far removed from standard broadcast bands. It has a highly controlled signal that can be detected only in the zone of the transmitter antenna. Broadcast zones can be arranged so they will not overlap. The receivers, therefore, will not receive signals from other nearby transmitters.

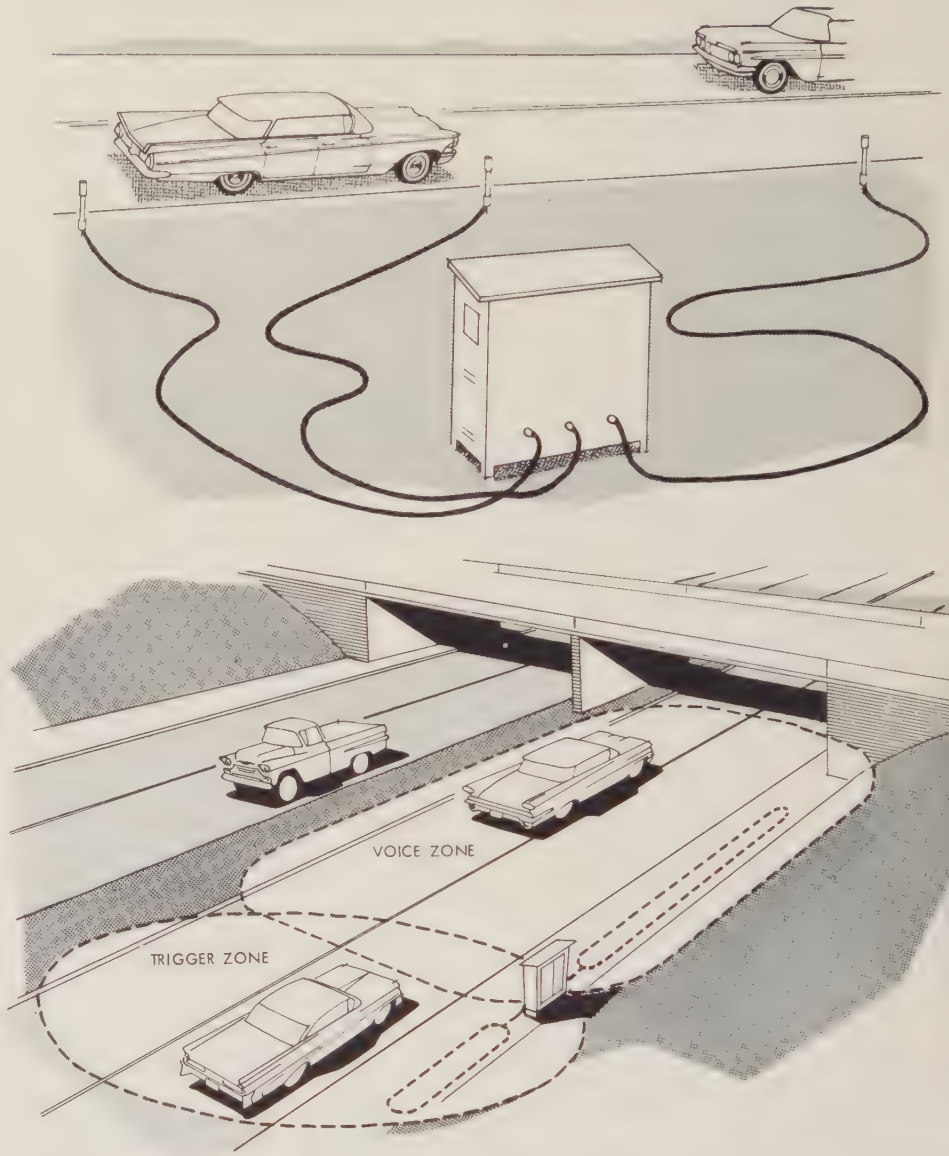


Fig. 1—The transmitters for the Hy-Com highway-to-car communications system can be operated by either ferrite core antennas (top) or by a radiating loop laid along the roadside (bottom). With the latter type of installation, a loop is extended about 50 ft from the communications enclosure in a direction toward oncoming traffic. This length of road is called the *trigger zone*. As soon as a car enters this zone a signal is picked up which sensitizes the receiver inside the car to receive a voice message. The message is transmitted as soon as the car enters the *voice zone*. The loop radiating the voice message can extend any reasonable distance. For a 500-ft length, for example, a car traveling 65 mph could receive a six-second message before it passed out of the voice zone range.

Either of two types of receivers may be used. One type, operated by self-contained batteries, can be mounted on the car door near the driver's ear. This type of receiver lends itself well to use on toll roads, as it can be installed or removed in a matter of seconds. The second type of receiver is permanently installed in the car and utilizes the standard car radio power amplifier and speaker. If the car radio is turned on it will be muted until the voice message from the roadside

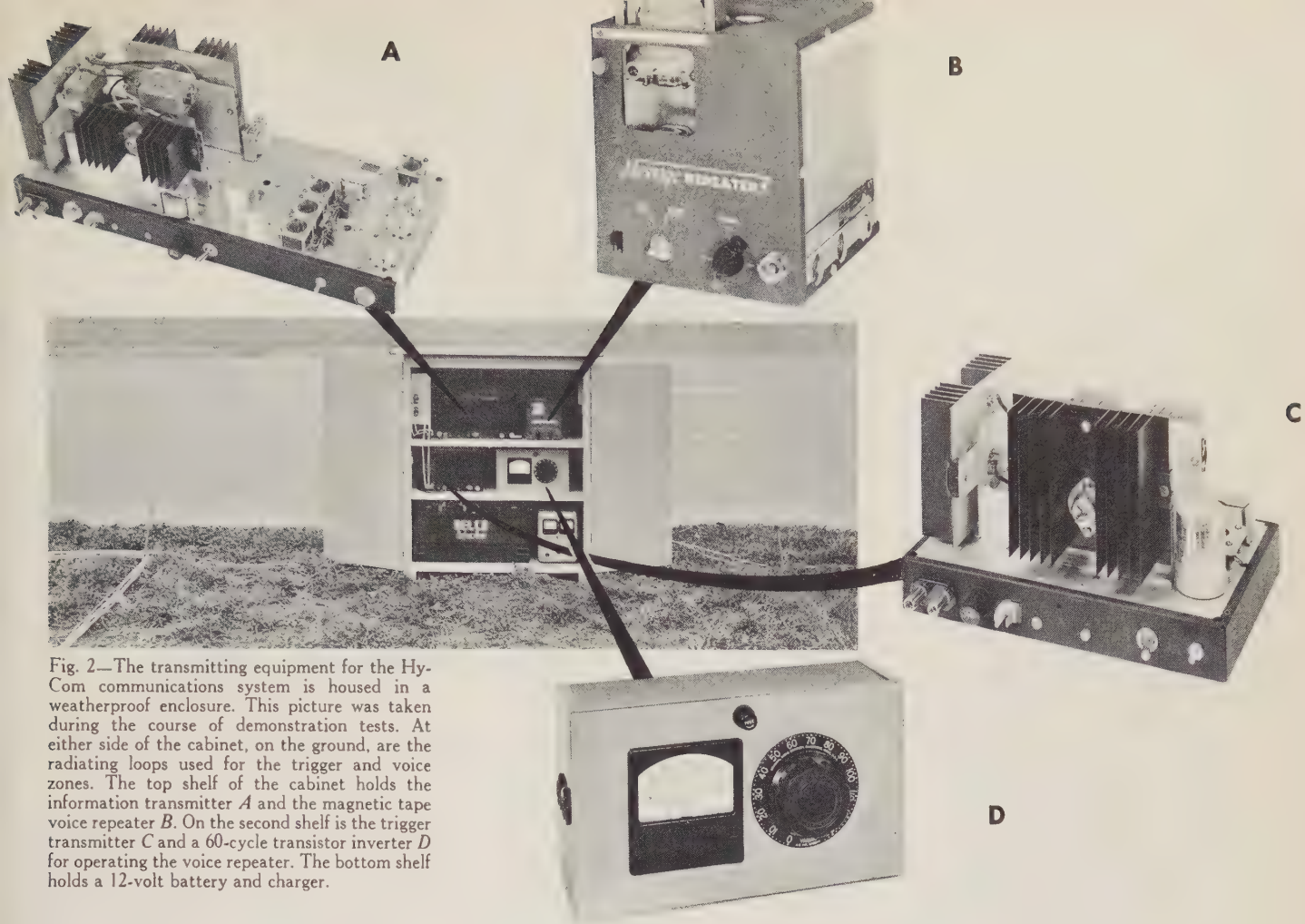


Fig. 2—The transmitting equipment for the Hy-Com communications system is housed in a weatherproof enclosure. This picture was taken during the course of demonstration tests. At either side of the cabinet, on the ground, are the radiating loops used for the trigger and voice zones. The top shelf of the cabinet holds the information transmitter *A* and the magnetic tape voice repeater *B*. On the second shelf is the trigger transmitter *C* and a 60-cycle transistor inverter *D* for operating the voice repeater. The bottom shelf holds a 12-volt battery and charger.

transmitter is completed. If the car radio is turned off, the transmitter signal instantly turns on the transistorized output stage of the car radio and puts the message through the loudspeaker. When used with a non-transistorized car radio, the message receiver includes an output stage. An adapter plug is used between the radio and speaker to permit interruption of the standard broadcast program.

The use of transistors in the receivers results in low power consumption. The receivers can operate continuously when the car ignition is turned on without heavy battery drain.

System Design Gives Controlled Message Area

The transmitting equipment of the Hy-Com communications system, contained in a weatherproof enclosure (Fig. 2), is easily portable for greater application flexibility.

The equipment includes two transmitters, a magnetic tape voice repeater, a 60-cycle transistor inverter for operating the voice repeater, and a 12-volt battery and charger. The transmitting equipment is not limited to the use of a tape voice repeater. Voice messages also may originate from microphones or a master control station, if telephone lines are available.

One of the transmitters sends out a continuous signal from a radiating loop extending about 50 ft from the enclosure and in a direction toward oncoming traffic. This length of road is called the *trigger zone*. The second transmitter sends out voice signals from a loop extending any reasonable distance along the roadside in the opposite direction. This length of road is called the *voice zone*.

The receiver in the car will not operate until the car enters the trigger zone. At this point, the signal from the trigger transmitter is picked up and the receiver is then sensitized for listening to the voice zone. As long as the voice information signal is picked up, the receiver is held on. As soon as the car passes beyond the range of the voice loop, the receiver reverts back to its insensitive condition and no further operation occurs until the car again passes through a trigger zone. On the receiver integrated with the car radio, the broadcast program is muted by the triggering signal.

The triggering function is desirable for two reasons. First, it prevents reception of a voice signal being transmitted to cars traveling in the opposite direction. Second, it prevents reception of a weak random voice radiation, which could conceivably be encountered under some conditions where power lines pick up the transmission and re-radiate it at some undesired location.

Primary Components are Transistorized

The trigger transmitter uses five transistors, draws from three to four amperes at twelve volts, and radiates about fifteen watts. The information transmitter uses seven transistors, including those in the audio system. It has filters for elimination of a carrier and one side band and draws an average of one ampere at twelve volts. The peak radiated power of the information transmitter is approximately 30 watts.

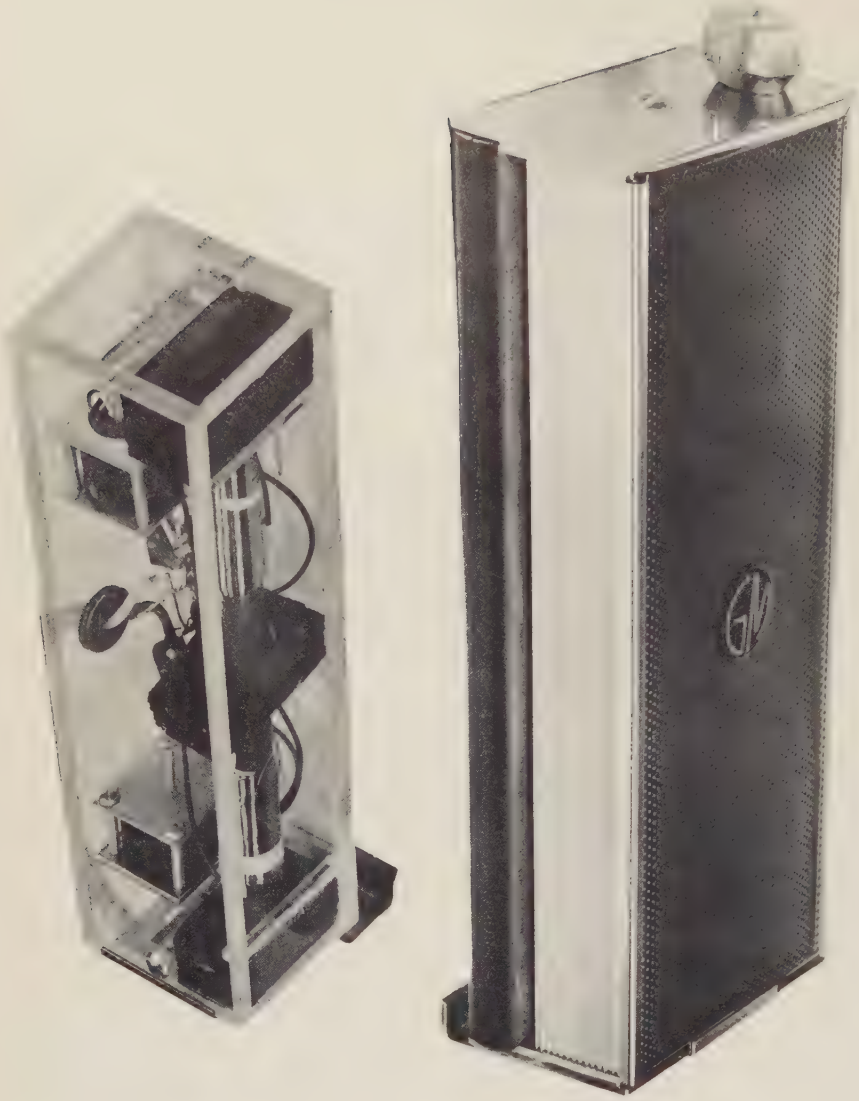


Fig. 3—The hang-on type receiver is operated by pen cell batteries and uses seven transistors for both triggering and reception. The pick-up loop, shown here in a clear plastic housing for demonstration purposes, mounts outside the car window.

The hang-on type receiver (Fig. 3) uses seven transistors for both triggering and reception. It is operated by pen cell batteries having a life expectancy of around 150 hours.

Hy-Com Suggests Varied Applications

Among the possible uses for the Hy-Com communications system are the following:

- Integration with police and highway department radio communications, as well as with helicopter traffic controls
- Assistance to highway officials in expediting and re-routing traffic flow by providing motorists with almost instantaneous trouble-ahead warnings
- Supplement to roadside traffic signs which may be overlooked, particularly if they are obscured by darkness, fog, snow, or mud.

Although developed to provide voice signals to motorists, Hy-Com could conceivably be applied as a communications medium for trains, taxiing aircraft, or small boats in docking zones.

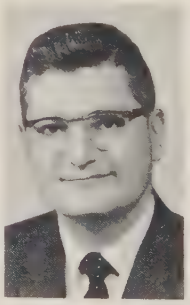
Contributors to July-Aug.-Sept. 1959 Issue of GENERAL MOTORS ENGINEERING JOURNAL

JACK W. BECKER, contributor of "Data Reduction Facility Provides Information to Evaluate Missile Performance Tests," is a senior project engineer at AC Spark Plug Division's Milwaukee, Wisconsin, plant. His present responsibilities include system design and evaluation of inertial guidance equipment for the Thor missile.

Mr. Becker joined AC Spark Plug in 1950 as a laboratory technician. His previous major projects have included design of airborne telemetry conditioning equipment, specification and procurement of telemetry data reduction equipment, and test equipment design on gun sight and bombing navigational computer projects.

Mr. Becker was granted the B.S.E.E. degree and the B.S. degree in mathematics from the University of Michigan in 1950. He received the Master's degree in electrical engineering from the University of Wisconsin in 1958.

The technical affiliations of Mr. Becker include membership in the American Institute of Electrical Engineers. He also is a member of Eta Kappa Nu, honorary society.

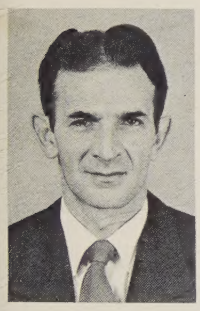


SIDNEY CARTER, contributor of "Confidential Relationships," and coordinator of this issue's "Notes About Inventions and Inventors," is a patent attorney in the General Motors Patent Section, Detroit Office. His re-

sponsibilities include review from the patent standpoint of GM contracts with the Government. He also is engaged in patent application work, patent investigations, and general licensing work.

Mr. Carter was graduated in 1942 from the College of the City of New York with the Bachelor of Chemical Engineering degree. He received the Bachelor of Laws degree in 1950 from George Washington University. His experience includes five years as patent examiner (1946 to 1951) in the U.S. Patent Office, and two years as legal officer, patents, in the Air Materiel Command, U.S. Air Force (1951 to 1953). He joined General Motors in 1953. During World War II, he served with the U.S. Air Corps as plans and operations officer.

He is a member of the American Patent Law Association, and the American Bar Association. His committee activities in these organizations include membership on the APLA Committee on Government Contracts, and the ABA Committee on Economic Matters for the Patent, Trademark, and Copyright Section.



JOHN E. CRAIG,

contributor of "A Simplified Method for Showing the Operating Sequence of Complex Manufacturing Equipment," is an electrical engineer with the GM Process Development Staff. He joined the Engineering Department of the Staff's Process Development Section in 1954 as a junior electrical engineer. He assumed his present position the following year.

Mr. Craig's current major projects include evaluation of different types of machine control systems and also electrical control engineering. Included in his previous projects was work connected with the first application of a static control system to manufacturing equipment in GM. (A static control system is one which eliminates conventional relays, thereby giving a machine control system with no moving parts.) He also did work on automatic hand tool testers, a transmission torus assembly machine, and the application of a static control system to a commutator molding machine.

Prior to joining GM he was employed as an electronics test engineer with the Weltronic Company.

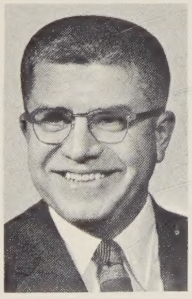
MILLARD A. FERGUSON,

contributor of "New Current Analyzer Determines Resistance Welder Performance," is a project engineer in the Electronics Department of the General Motors Process Development Staff. He currently is conducting research and development work in the machining field.

Mr. Ferguson joined GM in 1953 as a junior project engineer with the Process Development Section of the GM Process Development Staff, following employment with the Consumers Power Company. He was promoted to his present position in 1954.

Mr. Ferguson's projects have included designing and building test equipment for electrical checkout of aircraft wiring harnesses and relay boxes, and test equipment for checking automotive wiring. He also has worked on the development of high voltage power supplies for electrostatic spray painting, and has performed investigations into the use of ultrasonics in cleaning applications.

Mr. Ferguson received the Bachelor of Science degree in mathematics from Hillsdale College (Michigan) in 1942, and the B.S.E.E. degree from Rose Polytechnic Institute in 1947. He is a registered professional engineer in the state of Michigan and is a member of the American Welding Society, the Resistance Welding Instrumentation Committee of the A.I.E.E., and the GM Master Mechanics Subcommittee on Welding.



EUGENE B. JACKSON,

contributor of "Technical Literature—An Aid to the Engineer," is head librarian of the General Motors Research Laboratories, located at the GM Technical Center. He is responsible for the acquisition, processing, dissemination, and utilization of technical literature in support of the research program of the Research Laboratories and also the supply of technical literature to GM personnel both overseas and in the U.S.

Mr. Jackson joined the Research Laboratories as head librarian in 1956. Before joining GM he was chief, Division of Research Information, United States National Advisory Committee for Aeronautics, Washington, D.C. He also gained experience with other governmental technical information services and with both public and educational library systems.

Mr. Jackson graduated from the University of Illinois in 1938 with the B.S. in Library Science degree and obtained the M.A. in Library Science degree from the same school in 1942. He also received the B.S. degree from Purdue University in 1937. During World War II, he took part in the Army Specialized Training Program in Mechanical Engineering at Texas Technological College.

He is a member of the Institute of the Aeronautical Sciences, Special Libraries Association, American Documentation Institute Association, and Kappa Delta Pi, honorary education society. He has had articles published in *Special Libraries* and *Library Journal*. He is by government appointment a member of the Documentation Committee of the North Atlantic Treaty Organization's Advisory Group for Aeronautical Research and Development, Paris.

CLARENCE E. MORPHEW,

contributor of "Development of the Annual New Car Model—From Styling to Assembly," is staff engineer in charge of the Production Engineering Department of Cadillac Motor Car Division.

Mr. Morphew's Department functions as liaison between the Manufacturing, Purchasing, and Product Engineering Departments. The work of his Department includes interpretation of engineering drawings and specifications and the study and analysis of production problems. Another phase of his Department's work includes the assembly and teardown of rough and finish bucks of new car models and the study of the experimental road car build-up for possible production problems.

Mr. Morphew's engineering career has been spent entirely with Cadillac. He was originally employed in 1936 as a detail draftsman. Regular promotions have led to his present position, which he assumed in 1957. His job assignments

have included senior detailer, layout man, section engineer, and senior engineer. He also was assigned as a staff engineer at Cadillac's Cleveland, Ohio, Ordnance Plant.

His work has resulted in the grant of over six patents in the field of automotive design.

DONALD O. RUFF, contributor of "The Application of High Power Transistors to Audio Circuitry," is a senior project engineer in the Engineering Department of Delco Radio Division.

Mr. Ruff came to Delco Radio in 1951 as an electrical engineer in the Advanced Developments Section. His early projects included work on experimental tuner designs and electronic counter-measures devices for military use. In 1952 he began an investigation of transistor devices and their use in auto radios, after which an all-transistor super-heterodyne radio was completed. In improving upon this design, an intensive study of audio power stages was started to obtain more audio output. This eventually led to practical production designs of transistor power amplifiers for auto radios. Since then, Mr. Ruff has worked on the development of remote control devices and regulating devices employing power transistors.

Mr. Ruff attended Iowa State College at Ames, Iowa, receiving the B.S. and M.S. degrees in electrical engineering. He was employed for two years in the electronics laboratory of the Institute for Atomic Research at the college, while completing academic studies. He is a member of Eta Kappa Nu and Phi Kappa Phi, honorary societies, a member of the Institute of Radio Engineers and of the Professional Groups on "Audio" and "Electron Devices."

GORDON L. WEBSTER, contributor of the problem "Improve Projection-Weld Quality Through Statistical Methods" and the solution appearing in this issue, is a faculty member of the Production Engineering Department at General Motors Institute.

Mr. Webster joined General Motors in 1937 as a G.M.I. co-op student sponsored by AC Spark Plug Division. After graduating from G.M.I. in 1941, he worked as a time study engineer at AC until called for military service. Upon separation from service in 1946, he returned to AC as a time and motion analyst. In 1948 he joined the faculty of G.M.I.

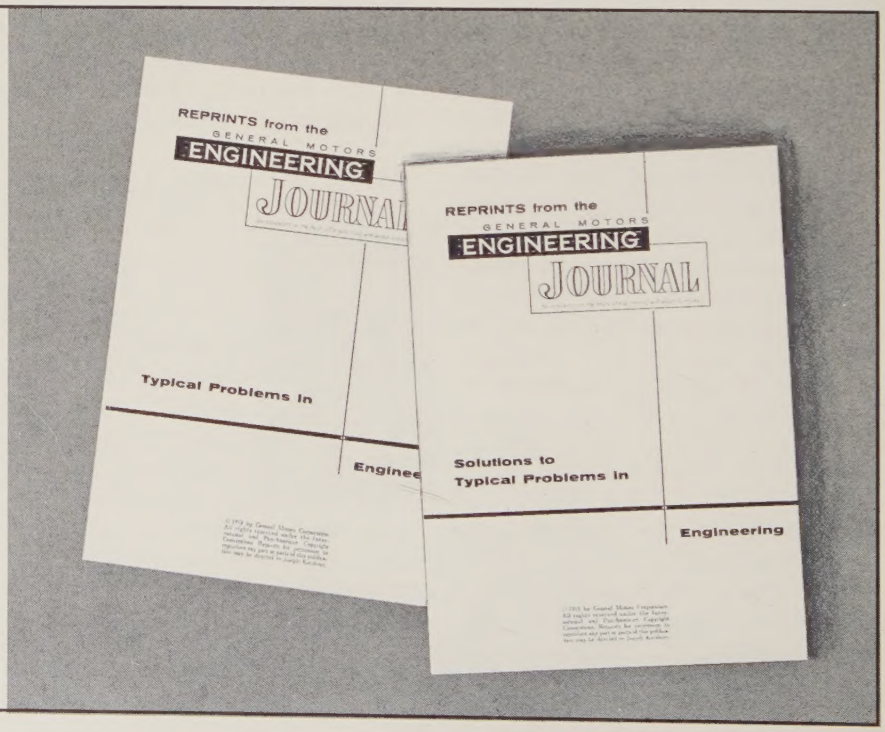
The teaching responsibilities of Mr. Webster include teaching courses in material handling and statistical methods in manufacturing for the co-operative engineering, Fifth Year and Thesis, and Technical Resident Training Programs.

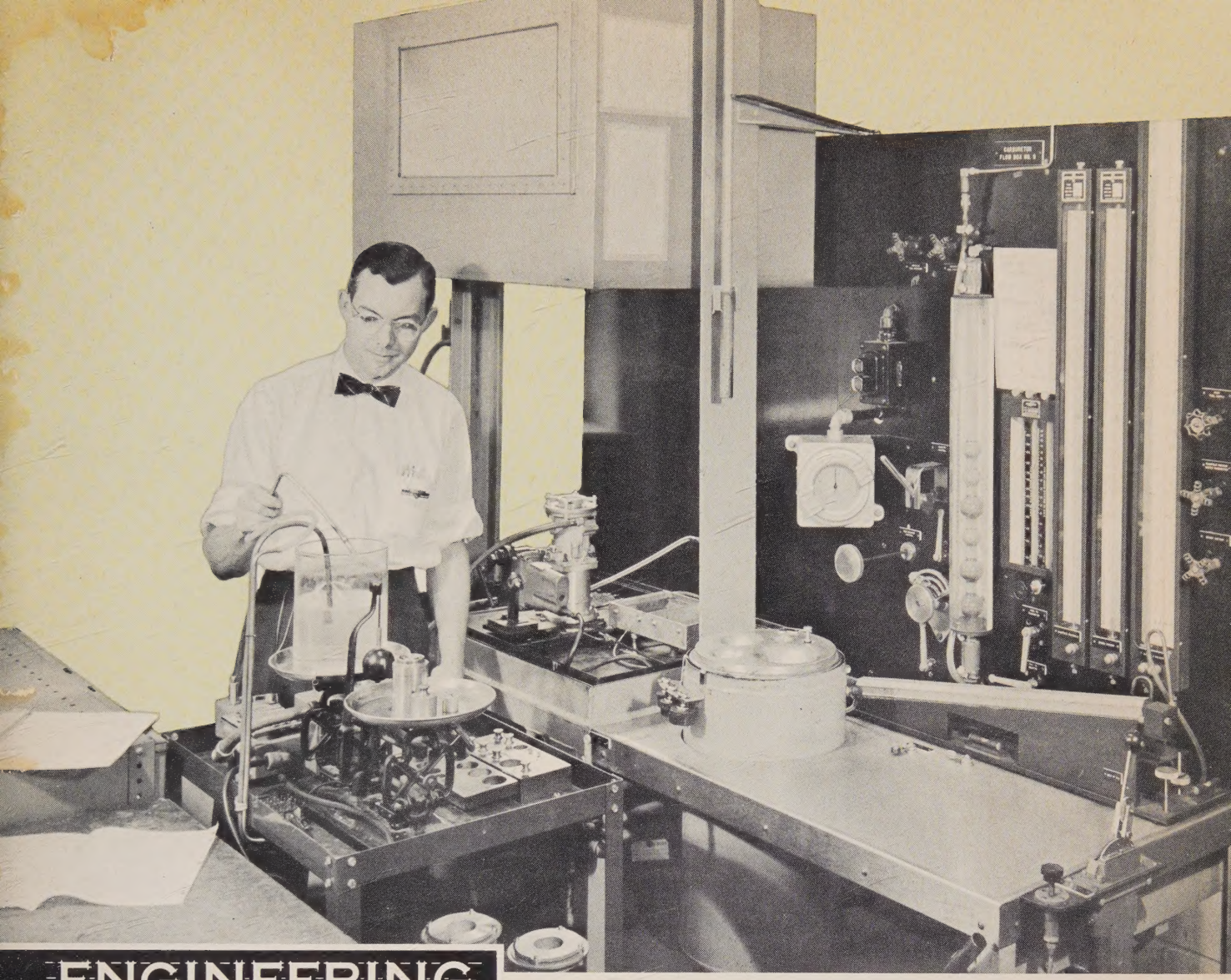
Mr. Webster received the B.I.E. degree from G.M.I. in 1950. He is a member of the American Society for Quality Control, the American Society for Engineering Education, the American Society of Mechanical Engineers, and Alpha Tau Iota, honorary society. He also is a member of the American Standards Association's sectional committee on safety code for industrial power trucks and the GM Statistical Methods committee.

REPRINTS OF TYPICAL PROBLEMS IN ENGINEERING AVAILABLE TO EDUCATORS

Reprints of over 30 typical problems in engineering and their solutions previously published in the General Motors Engineering Journal are now available to engineering educators. The problems and solutions are printed in separate books. Classroom quantities are available.

Educators interested in receiving the problem and solution reprints may write to the Educational Relations Section, Public Relations Staff, GM Technical Center, P.O. Box 177, North End Station, Detroit 2, Michigan.





ENGINEERING

ASSIGNMENT IN GM

The flow box is an important piece of test equipment used in carburetor development work at the Rochester Products Division. By means of this device, air flow and fuel flow through a carburetor can be measured accurately and the air-fuel ratio computed over the full range of operating conditions. Thus, the development engineer is afforded the opportunity of precise comparisons between a newly calibrated carburetor or a carburetor incorporating new design features and one of established characteristics. This sort of comparison is particularly helpful since flow box data are obtained under conditions similar to those found on an engine.

Rochester Products has thirteen such flow boxes, nine in product engineering and four in the quality control area. Since there are minor structural and operational differences in equipment, it is essential that all measuring instruments be carefully correlated to obtain uniformly reliable results on all equipment.

In the above photograph Russell Laidlaw, instrumentation engineer, is shown with equipment developed at Rochester Products for standardizing the flow meters used on each of the flow boxes. This equipment, consisting essentially of a torsion balance controlling an electrical timer, measures fuel by indicating the precise time required for a given weight of fuel to flow.

Below the raised enclosure hood is one of the venturi used for calibrating air measurement equipment. The orifice plate and calibrated inclined manometer can be seen in the foreground and the flow meter in the center of the flow box panel.

Mr. Laidlaw graduated from Cornell University in 1956 with the Bachelor of Electrical Engineering degree. Shortly thereafter, he joined the Test and Calibration Section at Rochester Products. He was first employed as a junior engineer working with carburetors and fuel injection.

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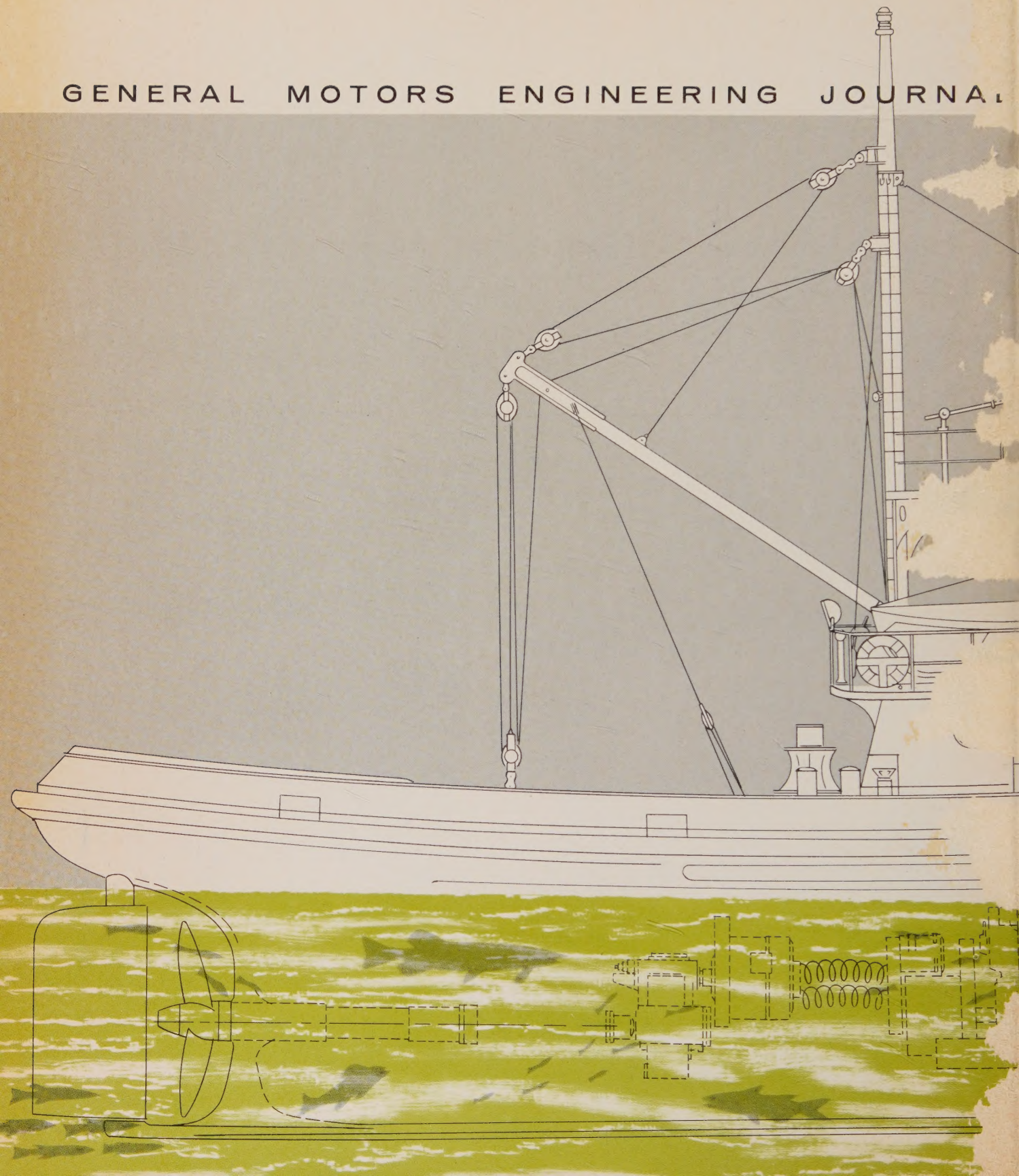
GENERAL MOTORS ENGINEERING JOURNAL